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Towards vibrant fish populations and sustainable fisheries that benefit all: Learning from the last 30 years to inform the next 30 years

Perspective Article

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Abstract

A common goal among fisheries science professionals, stakeholders, and rights holders is to ensure the persistence and resilience of vibrant fish populations and sustainable, equitable fisheries in diverse aquatic ecosystems, from small headwater streams to offshore pelagic waters. Achieving this goal requires a complex intersection of science and management, and a recognition of the interconnections among people, place, and fish that govern these tightly coupled socioecological and sociotechnical systems. The World Fisheries Congress (WFC) convenes every four years and provides a unique global forum to debate and discuss threats, issues, and opportunities facing fish populations and fisheries. The 2021 WFC meeting, hosted remotely in Adelaide, Australia, marked the 30th year since the first meeting was held in Athens, Greece, and provided an opportunity to reflect on progress made in the past 30 years and provide guidance for the future. We assembled a diverse team of individuals involved with the Adelaide WFC and reflected on the major challenges that faced fish and fisheries over the past 30 years, discussed progress toward overcoming those challenges, and then used themes that emerged during the Congress to identify issues and opportunities to improve sustainability in the world's fisheries for the next 30 years. Key future needs and opportunities identified include: rethinking fisheries management systems and modelling approaches, modernizing and integrating assessment and information systems, being responsive and flexible in addressing persistent and emerging threats to fish and fisheries, mainstreaming the human dimension of fisheries, rethinking governance, policy and compliance, and achieving equity and inclusion in fisheries. We also identified a number of cross-cutting themes including better understanding the role of fish as nutrition in a hungry world, adapting to climate change, embracing transdisciplinarity, respecting Indigenous knowledge systems, thinking ahead with foresight science, and working together across scales. By reflecting on the past and thinking about the future, we aim to provide guidance for achieving our mutual goal of sustaining vibrant fish populations and sustainable fisheries that benefit all. We hope that this prospective thinking can serve as a guide to i) assess progress towards achieving this lofty goal and ii) refine our path with input from new and emerging voices and approaches in fisheries science, management, and stewardship.

A Space for Ideas and Dialogue

The first World Fisheries Congress (WFC) was held in 1992 in Athens. Since then, the WFC has been held roughly on a quadrennial basis in Brisbane, Beijing, Vancouver, Yokohama, Edinburgh, Busan, and Adelaide. The WFC brings together knowledge generators, knowledge users, stakeholders, and rights holders from around the globe with interests and expertise in fish and fisheries. The stated goal of the first WFC was to "bring together fisheries scientists and managers in a nongovernment, nonpolitical, academic setting devoted to the sharing of research findings and the application of collective knowledge in enhancing the scientific management of fisheries resources for sustained human benefits" (Nielsen and Wespestad 1993). Aside from emphasizing that the conference is truly inclusive of all actors and expertise (including Indigenous ways of knowing as well as fisher and community knowledge) whilst creating a space for welcoming and training the next generation of fisheries professionals, not much has changed. By all accounts, the WFC has become *THE* event for the global fisheries science and management community to assemble and both share with and learn from each other. To say that the WFC has become a space for ideas and dialogue understates the true impact of the WFC on the fisheries science and management professions and global fisheries research and management.

The WFC held in Adelaide in 2021 was no different, despite that a global pandemic led to a postponement (originally scheduled for September 2020) and eventually an online-only conference format where participants were limited to virtual interactions given public health restrictions on both domestic and international travel. This has been a challenging time for all, yet the organizing team used their creativity to craft a conference experience that further extended the reach and impact of the event. The theme of the WFC in Adelaide was "Sharing our oceans and rivers: a vision for the world's fisheries." The theme emerged given the challenges of fishing sustainably and maintaining prosperous fishing communities from marine and inland systems where functional integrity and conservation values are facing increasing pressure. Fisheries are just one user of oceans and rivers, and that these systems increasingly have many users who need to consider trade-offs and cumulative effects of everyone's actions.

Reflecting on the Past and Providing Guidance for the Future

The 2021 WFC had a strong emphasis on documenting progress in the sustainable management of fisheries in the almost 30 years since the first WFC in Athens, while also projecting where we need and want to be in the next 30 years. A key outcome of the 2021 WFC was to identify actions needed over the next few decades to achieve the ***goal of ensuring that the world's marine, estuarine and freshwater ecosystems and fishery resources are vibrant and managed sustainably for the benefit of current and future generations***. In this paper, we reflect on the past and provide guidance for the future to achieve this lofty goal. To do so, we consider two key questions: 1) What were the major challenges facing fish/fisheries from the past 30 years and what progress has been made to address these challenges? 2) What needs to be done to achieve thriving fish populations and sustainable, equitable fisheries in the next 30 years?

To discuss these key questions, we provide a global perspective, spanning realms (e.g., marine, freshwater, estuarine), sectors (e.g., Indigenous, commercial ranging from small-scale to industrial, recreational, aquaculture, conservation), and disciplinary domains (e.g., oceanography, ecology/biology, sociology, governance, policy, legal, economics) with attention given to fish, ecosystems, people, and place. Our team of authors was drawn from the International Program Committee and plenary speakers from the 2021 WFC, as well as several early-career scholars. In sum, the 24 authors reside in 12 countries that span all continents (except Antarctica), with roughly equal gender balance, and are drawn from academia, industry, government (at various levels from regional to the Food and Agriculture Organization of the United Nations - FAO), and the nongovernmental sector. We acknowledge that our authorship team does not represent all perspectives, and that some voices, in particular Indigenous cultural perspectives, are not represented here. We recognize this as a major deficiency to this opinion piece, but have taken this as an opportunity to improve our perspectives. This paper is timely and given the diverse perspectives of authors (informed by participation in the WFC) we feel that these ideas are worth sharing with the broader fisheries science and management community.

Approach

All authors were asked to identify at least three topics for both the backward- and forward-looking perspectives with specific examples (including key references) based on their expertise, knowledge, and lived experiences. Contributions were then sorted into themes. These ideas were further informed by knowledge-sharing and lessons from the WFC, during which we conducted this exercise. Our ideas are shared in sequence, first presenting our reflections and then providing guidance for the future. For both questions, most themes had some level of disciplinary organization (e.g., human dimensions, governance, stock assessment) but, for the future, we also identified a number of cross-cutting themes that were less specific to a given discipline (e.g., climate change, fish and food systems, foresight science, Indigenous ways of knowing). We recognize that outputs from such types of exercises reflect the interests and expertise of those who participate so it is possible (if not even likely) that there are other examples or issues that have been overlooked. This is particularly evident for our reflections on the past 30 years (Question 1), where some of the examples are narrowly scoped. It is impossible to comprehensively review three decades of fisheries science and advancement here so we have focused on the major challenges and advancements in the field within the last 30 years and intentionally focused the majority of our effort on the prospective Question 2.

Q1 **What were the major challenges facing fish and fisheries over the past 30 years and what progress has been made?**

Over the past 30 years, fisheries have faced numerous challenges, six of the major ones and the progress to address them are discussed here.

Reconsidered how fisheries assessment and management are conducted

Over the past few decades, fisheries science has put increasing focus into managing fisheries and their associated ecosystems. Thirty years ago, conflicting stock assessments, and data analysis methods, as well as limited data or incomplete data resulted in a lack of management action, biomass decline, and stock collapses in many fisheries (Hilborn 2020). Management Strategy Evaluation (MSE) (Butterworth 2007, Punt et al. 2016), regarded as FAO best practice, is gradually being adopted (admittedly, mostly in developed nations) as a method for testing management decision-making rules in generalized operating models that capture a wider range of uncertainty than the single 'best assessment model' paradigm (Parma 2002; Kaplan 2021). MSE can evaluate performance trade-offs between competing objectives (e.g., conservation and optimal utilisation) of alternative management procedures. It is increasingly employed by fisheries managers stakeholders, and rights holders to select new management strategies or examine effectiveness of existing strategies.

Market-based instruments, including the global certification and ratings systems (e.g. Marine Stewardship Council, Seafood Watch, the International Seafood Sustainability Foundation, Global Seafood Ratings Alliance, and Friend of the Sea), have incentivised fisheries to improve their management and governance since commencing several decades ago. Now, nearly 30% of global wild production is certified, rated, or in a fisheries improvement project (Potts et al. 2017). Certification schemes have been seen as a particularly promising tool to address areas where traditional governance has been less impactful, such as global fisheries, by utilizing consumer power to affect market advantages and access. Certification has an impact on improving management processes through the requirement for implementation of management procedures that have been demonstrated to be robust and precautionary via MSE.

At the time of the first WFC, there was some awareness of the need for an ecosystem perspective, but no clear framework or even a definition in the context of fisheries existed. Since then, discussions were dominated by debates regarding the definitions and concepts of ecosystem-based management (EBM; Larkin 1996, Long et al. 2015) and then to sharpening them into more tangible management concepts [whether EBM across all users and components, or the more fisheries-focused ecosystem-based fisheries management (EBFM; Pikitch et al. 2004) or the ecosystem approach to fisheries management (EAF; FAO 2003)]. Now, we have largely moved on from debates about the concept's rationale, to actually implementing ecosystem-based approaches, which has included exploring the socio-political aspects beyond natural science considerations and learning from the longitudinal results of the earliest case studies where such more integrated management has been at least partially attempted (FAO 2009; Patrick and Link 2015a,b; Long et al. 2015).

Similarly in freshwater systems, early studies of inland fisheries focused on simple population fluctuations through time as a function of either fishing effort or threats such as climate, alternative water uses, and diversions (Welcomme 2016). However, in recent years, there has been a substantial shift in thinking, and recognition of the major role environmental drivers (such as river flow, habitat and climate conditions) have in the production of freshwater fisheries biomass and sustaining the diversity of fish assemblages (Hoeinghaus et al. 2009; Arthington et al. 2016). Although overfishing can occur in inland waters (Allan et al. 2005), many of the declines to inland fisheries come from external factors (e.g., water extraction, pollution, habitat degradation), and the management of these threats are now featuring in the management of freshwater ecosystems and inland fisheries globally (Cooke et al. 2016; Tickner et al. 2020). At this point, many of these issues remain but at least the issue has been formally acknowledged including by FAO. In 2015, FAO convened the first ever inland fisheries conference resulting in the "Rome Declaration" which presents ten steps needed to achieve responsible and sustainable inland fisheries (Taylor and Bartley 2016).

Fisheries management is now recognized as being conducted in a multiple-use environment, which must consider fisheries along with other issues and sectors - such as aquaculture, conservation, shipping, energy generation, and tourism, to name but a few. To fully capture the range of responses to dynamic systems (whether rivers or oceans), whose changes are intensified by climate change, a broader suite of environmental, social, and political conditions needs to be routinely considered and adapted (Szuwalski et al. 2016). All of these considerations - along with recognized limited and ineffective management of fisheries in many locations historically - has continually motivated a shift to more integrated systems (Link et al. 2019), though much more remains to be done.

Developed assessment and information systems

Assessment approaches and information systems (i.e., data gathering and information sharing) have also evolved substantially over the past 30 years, although they are still mainly focused on the biophysical systems and much less so on social and economic information. In the 1990s, the internet was in its earliest stages and assessment materials were available in paper reports with limited distribution. Today, bodies such as the International Council for the Exploration of the Sea and the U.S. National Oceanic and Atmospheric Administration follow transparency rules, attempting to share online not only the assessment processes but also the input data and outcomes (e.g., https://www.ices.dk/data/assessment-tools/Pages/transparent-assessment-framework.aspx). These statistics are often reported publicly using simplified metrics in a timely manner via the internet, enabling local managers, stakeholders, and rights holders to review and consider recent data for decision making. However, not all countries and regions have yet established such transparent systems, many remain capacity-limited, continue to have sparsely available data, or are challenged by the complexity of highly diverse multi-species, multi-fleet fisheries, the scale and dispersed nature of small-scale fisheries, or disputed maritime borders.

The methods used have also evolved. Models of single-species based population dynamics still dominate in many jurisdictions, but their best practice use includes frameworks that explore uncertainties and connect to clear harvest control rules (http://www.capamresearch.org/) and MSE options (Punt et al. 2016). They have also been complemented with an expanding diversity of tools for data poor situations (Dowling et al. 2016; Carruthers and Hordyk 2018) and clear guidance on the use of such tools (Harford et al 2021), as well as for multispecies fisheries and ecosystems (Plagányi et al. 2012). Nonetheless, failures of fisheries management in data (and capacity) poor regions of the world remains a critical area for fisheries throughout much of the world. New methods for direct estimates of abundance (e.g., close kin; Bravington et al. 2016) will hopefully reduce the over-reliance on fishery dependent data.

Information handling has also advanced. While data remain a limiting factor, particularly in terms of coverage of multiple ecosystem components, the volume of available data has grown extensively over the last few decades (Farley et al. 2018). While biological surveys and fisheries dependent data remain the two most common forms of data available for stock assessment, significant advances have been made towards including data from different sources such as genetics and genomics (Bravington et al. 2016), including environmental DNA (Rourke et al. 2021), remote sensing (of habitats and fishing fleets, e.g., global fishing watch; Nugent 2019), supply chain tracking, and acoustics. Handling these data presents a significant challenge for operators, researchers, and management bodies. Transparency and knowledge sharing also means that interactive and updating online information systems (such as FAO GlobeFish https://www.fao.org/in-action/globefish/globefish-home/en/), which are accessible by the public or at the very least stakeholders and rights holders, have become an increasingly expected norm, especially among developed nations. Developments in assessment methodology and information systems have put fisheries management on a path towards success although more work is needed to incorporate diverse data streams in a more timely manner.

Documented threats for fish and fisheries

Over the past 30 years, much effort has focused on documenting threats facing fisheries and aquatic ecosystems. From pollution to illegal, unreported and unregulated (IUU) fishing, to habitat alteration and loss, bycatch, climate change, and recently Covid-19, the negative impacts are common and extensive. There have also been many successes in the marine realm (e.g., bycatch reduction; Squires et al. 2018; Komoroske and Lewison 2015), though there is insufficient space to explore all of these topics in detail here. Notably, however, we are now beginning to realize that these (and other issues) are also problematic in inland waters (Reid et al. 2019). Indeed, recognizing that freshwater fish populations are in decline because of a myriad of threats (Dudgeon et al. 2006, Reid et al. 2019) has been an important development, but we have yet to successfully reverse that trend (Harrison et al. 2018; Tickner et al. 2020). The effects of dams on fish, for example, have now been well documented with much effort focused on identifying environmental flows (Poff and Zimmerman 2010) and development of effective fish passage (Schilt 2007; Silva et al. 2018) and even, in a few countries, some dam removal (Bednarek 2001; Magilligan et al. 2016). Yet dam construction has continued if not escalated throughout the world (Zarfl et al. 2015), with more dams being developed and planned, particularly in mega-diverse regions, where there can be dire consequences for biodiversity, local livelihoods, and nutritional security (Winemiller et al. 2016). Invasive species are also now well recognized for their threats to freshwaters (and increasingly in marine systems) yet introductions (intentional and accidental) continue (Havel et al. 2015).

A threat that became apparent during the last few decades was the effect of natural disasters on fishing communities, which was exemplified by the 2004 Indian Ocean Earthquake and Tsunami, devastating to coastal fishing communities (De Silva and Yamao 2007). Extreme flood and drought events in freshwater ecosystems have impacted the recreational fishing sector (e.g., reduced fishing opportunities, loss of income for fishing guides that depend on fishing for their livelihoods; Schneckenburger, and Aukerman 2002) and small-scale commercial and subsistence fishing communities (e.g., impacts on nutritional security and livelihoods; Adeoti et al. 2010; Lennox et al. 2019). The frequency of some of these kinds of shocks appears to be growing (Cottrell et al 2019) and is likely to continue to do so under climate change (Oliver et al 2019).

The growing demand for food and nutritional security has driven a fresh perspective on fisheries, including the introduction of the concept of nutritional Maximum Sustainable Yield (Robinson et al 2022). Changing market forces have also seen an accelerating interest in increasing aquaculture production (Naylor et al. 2009; Bostock et al. 2010), with parallel interest in doing so in ways that minimize harm to aquatic ecosystems (Pillay 2008) and improve fish welfare (Rasco et al. 2015). We recognize the important competitive and synergistic linkages between aquaculture and other fisheries sectors (e.g., drawing from a common pool of science and technology, market demand for fish and market competition, fishmeal demand, aquatic space competition, competition for policy maker attention and resources for innovation investment).

Acknowledged the role of human dimensions in fisheries management

Over the past 30 years, fisheries science has increasingly recognized the importance of understanding and incorporating the human dimensions into fisheries management and conservation measures, policy, and legal frameworks. An ecosystem approach to fisheries should not only be about ensuring the ecological integrity of fisheries, but also about creating an enabling regulatory framework and environment for fisheries sustainability by strengthening social, economic, and institutional aspects in fisheries (De Young et al. 2008; FAO 2009). The human dimensions in fisheries management can be perceived through, for instance, integrated ecosystem assessments (e.g., environmental, socio-cultural impact assessments), participatory arrangements (e.g., co-management, community-based management), through the specific lenses of certain groups such as women (Williams, 2008; FAO 2009), and by following a human rights-based approach to small-scale fisheries management and governance (FAO, 2015).

Early human dimension efforts had four primary foci: 1) fisheries economics, 2) aspects of social science focused on characterizing fisher behaviours and perspectives, 3) the importance of all nodes of the fish value chains, not just fishing, and 4) the importance of specific social groups. Early fisheries economics efforts tended to focus on important fishing management problems, emphasizing creation of a solid foundation for further development of models relevant to policy makers and managers (Bjørndal and Munro 2012). Yet, there have also been criticisms that fisheries economics has been too focused on theoretical debates rather than trying to solve pressing management problems (Wilen 2000). Fisheries economists are credited with the widespread development and use of bioeconomic models (often simulation-based) for investigating and implementing different management plans (Clark 1985). These bioeconomic approaches have also supported a shift to Maximum Economic Yield as the dictate of fisheries reference points (as opposed to Maximum Sustainable Yield based rules) in some jurisdictions (e.g., Australia).

For social scientists, a fishery has long been regarded as a social system (or what we now refer to as a social-ecological system) which includes fish as well as resource users and the rest of the support infrastructure and industry (Ditton 1996). For the last 30 years, most human dimensions research on fishing in developed countries has used mail survey and telephone (or intercept) interview techniques but in the last decade there has been more focus on using electronic methods (e.g., email surveys, social media distribution). In inland systems, much work has focused on the recreational angling sector to understand motivations, behaviours, management preferences, and how these vary among different segments (e.g., specialized anglers vs generalist anglers; Arlinghaus et al. 2013). In the marine realm, there has been more focus on the commercial sector with particular emphasis on conflicts (Pomeroy et al. 2007), but there are growing efforts to categorize the scale and scope of recreational fisheries as well (MRIP 2017). There has also been a recognition that fisheries social science has much to offer in terms of social struggles and justice (Bavinck et al. 2018; see section on equity below). Some natural resource management agencies have developed internal capacity for human dimensions research to support management.

Social groups that have been gradually recognized as critical but overlooked actors in fisheries include small-scale fishers (Hidden Harvests 2012; FAO 2015), women (Gopal et al. 2020), and Indigenous peoples (Jentoft et al. 2019). In the past decades, more efforts have been made, especially in developing countries, to better understand these groups, recognize and protect their rights, and enhance their agency and capacity to participate in fisheries management and decision-making process of their concern. The development, adoption and implementation of the Voluntary Guidelines for Securing Sustainable Small-Scale Fisheries (SSF Guidelines; FAO 2015) is the most comprehensive case of a participatory process to secure the rights of the majority of fishers, based on the human rights-based approach (Nakamura 2022). Continued exploration and integration of the human dimensions of fisheries will be critical for informing sustainable management and supporting the people and communities who depend on fisheries.

Enhanced understanding of weaknesses in fisheries governance, policy, and compliance

During the past 30 years, there were several advances in understanding and even overcoming some of the weaknesses in fisheries governance, policy, and compliance. A great part of this progress in the marine realm stemmed from the 1992 United Nations (UN) Conference on Environment and Development (UNCED), which strongly endorsed the precautionary principle, biodiversity protection, climate change concerns, and the need to manage and conserve high seas fisheries (Freestone 1999).

Following the UNCED, its recommendations saw major advances in implementation, notably the adoption of key international legal instruments (e.g., FAO Compliance Agreement 1993, UN Fish Stocks Agreement 1995, FAO Code of Conduct for Responsible Fisheries 1995 (CCRF)), the establishment of new regional fisheries management organizations (e.g., Indian Ocean Tuna Commission in 1996, Western and Central Pacific Fisheries Commission in 2004), the formal adoption of the ecosystem approach to fisheries management (Reykjavik Declaration 2001), and the increased concern with conservation of deep-sea fisheries, habitats, and vulnerable marine ecosystems (Garcia et al. 2014). Additionally, the international agenda expanded as part of the Millennium Development Goals of 2000 and later the Sustainable Development Goals of 2015, broadening efforts to integrate various goals to the fisheries context (Said and Chuenpagdee 2019). In freshwater systems, the Rome Declaration (see https://www.fao.org/inland-fisheries/topics/detail/en/c/1142047/) includes ten steps to responsible inland fisheries with explicit calls for improvements in governance (see Cooke et al. 2016). Yet, challenges remain with little evidence of widespread improvements (Lynch et al. 2020; Cooke et al. 2021), and certain of these key instruments being technically narrow in their approaches, especially with respect to the human dimensions.

Despite the increased awareness about the need to shift from fisheries management to fisheries governance (Chuenpagdee and Jentoft 2018), the transition has not been easy. Fisheries problems are complex and require insights from interdisciplinary and transdisciplinary research, and nuanced approaches like collaborative and interactive governance frameworks (see for instance Kooiman et al. 2005; Ostrom 2010). Fisheries research has certainly grown and expanded to incorporate a broad array of knowledge, including those of local and Indigenous fishers - though rarely women fishers (e.g., Short et al. 2020) - which has helped improve governance. Yet, more needs to be done considering the additional demands on the governance systems at all levels and scales, as the aquatic ecosystems continue to face pressures and stressors affecting their productivity and health.

The last 30 years of legal and policy developments were largely focused on the environmental component of fisheries sustainability, resulting in a limited coverage of social dimensions, human rights, and protection of vulnerable groups (Papanicolopulu 2018; Nakamura 2022). Most of the existing international instruments addressing social aspects in fisheries are non-binding, including those adopted under the auspices of the FAO (Tenure Guidelines 2012, Small-Scale Fisheries Guidelines 2014) and the

UN Human Rights Council (UN Declaration on Peasant's Rights 2018). These instruments, nevertheless, enshrine the human rights-based approach to fisheries whilst fostering the protection and empowerment of small-scale fisheries holistically, covering issues of social development, gender, indigenous peoples, migrants, and other vulnerable groups. Efforts to elevate fisheries governance, policy and compliance are beginning to yield benefits, but more work is certainly needed.

Acknowledged need for gender equity and inclusion

While social equity is related to many factors, gender equity serves as a suitable case study because gender researchers have made significant conceptual contributions relevant to all human dimensions. A major theoretical contribution has been the intersectional nature of identity underlying social inequalities (Crenshaw, 1989). Biological, social, and cultural categories, including gender, race, income, caste, and class interact, creating systemic inequalities. In fisheries, different groups of women experience resource access and the impacts of resource appropriation in different ways (e.g., Ferguson 2021). Gender scholars have also developed the field of feminist political ecology that favours diagnosis of conditions at multiple scales, takes into account gendered rights and responsibilities, economic growth, and structural and political situations encountered (Resurreccion, 2017). It has been applied to complex fisheries management conflicts such as the social inequities across gender, race, and class relations of the Newfoundland and Labrador cod stocks of Canada (Bavington, et al., 2004) and the legal schemes applied in wetlands protection in Tonle Sap, Cambodia (Gillespie and Perry, 2018).

After a promising start arising out of the 1984 FAO Strategy for Fisheries Management and Development, and the inclusion of women in some early fisheries development programs such as the first two phases of the Bay of Bengal Programme, the inclusion of women dropped off the fisheries agendas in the early 1990s. The disconnect between international human rights and fisheries law evinced the need to make clear and explicit linkages between fisheries and gender in international fisheries instruments. Nevertheless, the adoption of the SSF Guidelines, which follows the principles of gender equality and equity, non-discrimination, and contains a chapter entirely dedicated to gender equality (FAO 2015) is coupled with some national and regional impetus to address the roles and needs of women and social inclusion in fisheries. Some progress has been made, although still in its early stages, to include gender in fisheries research and development programs, recognize the important role women play in fisheries, and ensure special attention to them in fisheries value chains (e.g., Fragoundes and

Gerrard 2018; Graham and D'Andrea 2021). From an assessment of the implementation of policy intentions in three Pacific countries, however, Lawless et al. (2021) caution that the commitments often are diluted or ignored in practice. Similar conclusions would be drawn if such studies were made in other regions and globally.

A significant gap in knowledge to guide gender equity and inclusion policies is the great dearth of gender-disaggregated data. In 2012, the Hidden Harvests report (World Bank, FAO, WorldFish, 2012) provided a first rough estimate of the number of women in small scale fisheries value chains (estimated to be 47% of the workers), and this is being updated in the forthcoming Illuminating Hidden Harvests study (due 2022). The FAO State of Fisheries and Aquaculture 2016 biennial report was the first to produce a table of gender-disaggregated statistics of labor in the fishing/fish farming. Over the past 30 years, there have been early efforts that acknowledge the need for gender equity and inclusion within the sector. More work is urgently needed but there have been some recent developments that show great promise. Similar conclusions would be drawn for other social equity dimensions.

Q2. What needs to be done to achieve sustainable and vibrant fish populations and fisheries in the next 30 years?

Over the next 30 years, we need to invest effort in addressing additional challenges to achieve thriving fish populations and sustainable, equitable fisheries. Here, we discuss each in turn and consider specific actions needed for each (See Figure 1).

Rethinking fisheries resources and ecosystem management systems

The inertia of history means it is exceptionally unlikely that the historical form of fisheries institutions and decision-making processes will radically change (Fulton et al. 2021). Nevertheless, the growing appreciation is that even with the best of intentions historical fisheries management has not delivered sustainable ecosystem-level exploitation (e.g., Link 2021). New challenges of global change (Tittensor et al. 2021) and ecosystem-based management (EBM) perspectives demand both a more inclusive and agile approach. Inclusion extends to the scope of the system implications considered in management decision making processes and in the people whose interests must be considered. This does not mean there will be a wholesale abandonment of current core fisheries resource and ecosystem management concepts. Instead, concepts like Maximum Sustainable Yield will continue to evolve to encompass multispecies sustainability and entire system–level dynamics as they have begun to do (Mace 2001; Thorpe 2019).

Management decision making processes will incorporate ancillary information. This can be either informally, as is the case in Alaska (where ecosystem indicators are reported alongside formal stock assessments; Dorn and Zador 2020), or more formally in explicitly multispecies and ecosystem-oriented harvest strategies (Pascoe et al. 2020). This could begin by supplementing existing single-species management methods with additional checks and indicators derived from environmental data streams or ecosystem models (e.g., Heath et al. 2017; Howell et al. 2021). However, we anticipate widespread use of harvest strategies that intentionally manage large numbers of species together, as has been done in Western Australia for some time now using indicator species concepts and leveraging life history characteristics (Newman et al. 2018).

Moreover, management systems are already looking beyond simple stock management to the broader human dimensions of fisheries and the many drivers of fisheries. More explicitly recognizing how trade-offs between economic, social, and environmental objectives constrain sustainable harvesting options (e.g., Briton et al. 2020) and considering climate change influence on reference points (e.g., Holsman et al. 2020) are early steps along that path. Significant challenges remain in finding tangible means of doing this in jurisdictions with low fisheries science and management capacity. In these systems, the social dimensions are most critical. Improvements in communication of the processes and advice will be key to change and adoption. There are opportunities to rethink fisheries resources and management systems such that they are placed within a broader context.

Modernizing and integrating assessment and information systems

The heterogeneity in data availability and assessment capacity globally remains a challenge and one that needs to be addressed urgently if the health of fish stocks and ecosystems are to be universally assessed. The need for social and economic data needs critical review. Development of highly informative monitoring and data collection programs is essential, and their cost-effectiveness can be measured via MSE in terms of reduced uncertainty and management procedure performance (Punt et al. 2016). However, the lack of inclusive social dimensions of current MSE approaches means they are unlikely to be suitable beyond their current fisheries resource and ecosystems focus. While many new assessment methods and data streams exist, understanding how to best utilize them takes time - as evidenced by the lively discussions surrounding the most appropriate use of integrated population models (Arnold et al. 2018), trait-based approaches (Barnett et al. 2019), ecosystem models (Fulton 2010; Perryman et al 2021), environmental DNA methods (Jeunen et al. 2019; Sigsgaard et al. 2020; Gilbey et al. 2021), data-limited assessment methods (Smith et al. 2009; Carruthers and Hordyk 2018) and the like.

Experience will help this evolution, as the transfer of expertise is assisted by training programs and capacity building - supported by initiatives such as the Data-Limited Methods Toolkit (Carruthers and Hordyk 2018) and FishPath (https://www.fishpath.org/; Dowling et al 2016). More will be needed though, as well laid out by Punt et al. (2020). As a start, solid advances can be made by implementing software engineering practices, such as human-centred design and broader use of code versioning and repositories, which are shareable through platforms such as GitHub (https://github.com/). In addition, there is opportunity for strategic use of online (cloud) computing power and collaborating with experts in software engineering, visualisation platforms, and human information processing [such as specialists in gamification and serious gaming (dos Santos et al. 2019)].

Increasing familiarity with the tools and having broader system perspectives will also help fisheries address broader questions more easily - such as risk assessment tools, for example, Ecological Risk Assessment for the Effects of Fishing (Hobday et al. 2011) or Integrated Ecosystem Assessments (DePiper et al. 2017, Harvey et al. 2021), ecosystem scale models that can be rapidly applied to fished systems (e.g., Mizer; Scott et al 2014), or multispecies models tailored to deliver information in formats that management processes are familiar with [e.g., the Model of Intermediate Complexity for Ecosystem assessments applied by Angelini et al. (2016) and Thorson et al. (2019)]. The collation and transmission of information (both raw data and processed products tailored to decision maker needs) is also foreseen to be a growing need into the future, with the ambition to deliver updated information in near real time in a format and on platforms that are widely accessible (e.g., on mobile devices) but also fit for purpose. This can already be seen in near real time sharing of effort distributions and bycatch to assist with targeting (e.g., Hazen et al. 2018) and compliance (Kurekin et al. 2019; Nugent 2019) and the increasing use of operational and seasonal forecasts to improve fisheries efficiency or as a basis for dynamic oceans management (Maxwell et al. 2015).

Transparent knowledge sharing, in its truest sense - a multi-way flow of information, that actively engages with stakeholder/manager/rightsholder interests and perspectives - will also require incorporation of specialist knowledge brokers into fisheries science teams (Cvitanovic et al. 2015). The field would also benefit from collaboration with communications specialists who understand how people receive and interpret information - this will be important as increasingly large audiences need to be engaged or in contentious circumstances (Condie and Condie 2021), such as when there is a clash between sectors, whether that is two commercial sectors or between conservation and fisheries or between cultural and economic objectives (Coulthard et al. 2011; Lester et al. 2017; Crona et al. 2021). Evidence syntheses such as systematic reviews also hold great promise for ensuring that decision makers are provided with rigorous and comprehensive assessments of the best available evidence on a given topic – something that has yet to be fully embraced in fisheries assessment and management (Cooke et al. 2017).

Ensuring equitable access to information also means that solutions (whether technological or facilitated by communicators) need to come in a form that can be shared more broadly and are not only available to a subset of those interested in the fisheries. Avoiding the marginalisation of those groups which are also at the low ends of power imbalances is important (Crona et al. 2021; Tigchelaar et al. 2021; Farmery et al. 2022). Similarly, there will need to be an expansion of assessment and reporting of a wider range of indicators as the values aspects of blue foods expand (e.g., nutritional value, carbon footprint, ecosystem footprint, inclusivity, and respect for people in value chain; Parker et al. 2018; Golden et al. 2021).

Modernization and access to technologies (e.g., smartphones and applications) have enhanced the ability to integrate the society into fisheries assessments through the development of citizen science platforms. These platforms have the potential to supplement existing data sets whilst contributing to improved relations between scientists, the public and government agencies (Bonney et al. 2021). Yet, the integration and translation of the results of citizen science projects into effective fisheries management is still in its infancy (Fulton et al. 2019). This integrated assessment has great potential to be explored and developed for both marine and inland, as well as small-scale and recreational fisheries (Fariclough et al. 2014; Gundelund et al. 2021). Access to technology, even mobile phones, is not equal in most societies and this needs to be considered. Data science approaches such as data feminism are needed. These take account of the political and social activism needed to collect, analyse, and project to decision-makers and the public the importance of data outside formal data collections but critical to targeting action and making decisions (D'ignazio and Klein 2020). For example, this approach could help bridge the results of numerous small-scale projects in many countries documenting the extent of work that women undertake in fisheries while formal national fisheries data will report that no women are engaged in fisheries. Modernizing fisheries assessment and information systems is necessary and would help to enable science-based management of aquatic resources.

Addressing persistent and emerging threats to fish and fisheries

Some persistent and emerging threats are common to fish and fisheries regardless of system type. Increasing fish trade and climate change, for example, have global ramifications across aquatic systems. These global processes often have unexpected interactions and the resulting consequences for fish and fisheries are difficult to predict (Staudinger et al. 2021). For example, emerging aquatic diseases can be driven by multiple intersecting stressors that threaten fish and fisheries. Coordinated global aquatic disease surveillance programs can help identify conditions that lead to emergence or transmission and develop interventions that can be used to treat diseases in wild fish at a grand scale (Peeler and Ernst 2019). Likewise, intensifying global climate change is propelling aquatic ecosystems toward irreversible transformations. While transformations have occurred in the past, the current rate of change and synergistic effects are unprecedented and unpredictable (Thompson et al. 2021). For example, extreme climate events, including fires, droughts, floods, are increasing in frequency with documented severe impacts to freshwater fish (Silva et al. 2020; Sheldon et al. 2021, Stocks et al. 2021).

Freshwater ecosystems are notable systems at extreme risk (Albert et al. 2020), and action within the next decades will be critical to conserve them and conserve inland fisheries. Tickner et al. (2020) present an “Emergency Recovery Plan” to address the following priority actions: accelerating implementation of environmental flows; improving water quality; protecting and restoring critical habitats; managing the exploitation of freshwater ecosystem resources, especially species and riverine aggregates; preventing and controlling non-native species invasions; and safeguarding and restoring river connectivity. This plan is gaining traction within the global conservation community (Twardek et al. 2021) and its priority actions will be particularly critical for resolving transboundary river issues and conflicts between diverse freshwater users. As the frontier of hydropower and river damming moves towards large, tropical, transboundary rivers (e.g., Amazon, Mekong), integrated and coordinated international management will become fundamental to halt fisheries declines (Van Damme et al. 2019). Likewise, as demand on irrigated agriculture to feed the world increases, improved regulated flow management measures (Stuart et al. 2019) and devices to reduce fisheries losses to irrigation systems (Boys et al. 2021) will be essential to avoid scenarios where increasing food production in one sector decreases it in another (Lynch et al. 2019). Importantly, management tools that have helped improve sustainability of marine fisheries, such as protected areas and reserve systems, can help address species declines and long-term fisheries sustainability in inland systems (Hermoso et al. 2016; Koning et al. 2020).

Estuarine and marine systems also face substantial threats. Development and damming of freshwater systems also impact the downstream estuarine systems by reducing freshwater input subsequently impacting the water quality and geomorphological processes within estuaries (Gillanders et al. 2022) and impacting fisheries where connectivity between aquatic realms is critical (Crook et al. In Press). Major cities are also often situated on estuaries adding additional threats associated with urbanization and coastal reconstruction. In marine systems, the increasing range of activities including fisheries and aquaculture, shipping, land reclamation, and renewable energy (e.g., wind and wave energy) means that these systems are now highly contested with potential for conflict among users. These intensive anthropogenic activities also lead to cumulative impacts on marine systems, reducing available ecosystem spaces, impacting the health of the systems and their dependent organisms. Increasingly spatial cumulative impact assessments are undertaken but rarely have they been validated with empirical data and the range of stressors are often viewed as having additive effects. Many threats, including emerging ones, continue to plague fisheries and aquatic systems. Efforts that attempt to understand and mitigate those threats are essential if we are to ensure the future viability of fish populations and fisheries.

Integrating the conceptual frameworks of biological and social scientists

Although the last thirty years have seen greater appreciation of the human dimension of fisheries, including through discussions emanating from previous WFCs (see Liguori et al. 2005), collaborative effort is still needed to integrate the conceptual frameworks and understandings of natural and social scientists (Hall-Arber et al. 2009). Indeed, although there are persistent information needs on biological (and environmental) aspects of fisheries, it is often people and human behaviour that dictates the ultimate success of any fisheries management actions (Hilborn 2007). Efforts to understand the perceived barriers to integrating human dimensions knowledge and concepts into fisheries science and management have been informative (e.g., Fox et al. 2006, Hall-Arber et al. 2009). Fox et al. (2006) identified barriers including the lack of common vocabulary between biologists and social scientists, the lack of funding for collaborative work, and limited opportunities for interdisciplinary collaboration. Hall-Arber et al. (2009) addressed models and means for integrating quantitative and qualitative data. Fortunately, efforts to address these issues are expanding, and much can be learned from existing and emerging examples. For example, Bennett et al. (2017) outlined a roadmap for mainstreaming human dimensions more broadly in environmental management and conservation sectors. Importantly, recognition of the critical value of Indigenous knowledge in fisheries management and conservation is increasing - particularly in the context of bridging these knowledges to better inform existing science-based decision-making (Crook et al. 2016; Diz and Morgera 2018; Reid et al. 2021; McKinley et al. 2022).

Notable to fisheries is the need to build personal and institutional capacity for human dimensions work and ensure that it is fully integrated into both knowledge generating and application processes. This involves reflexivity, that is, the researchers and their institutional approaches need to understand that their work and approaches are both cause and effect in the fisheries systems they seek to improve, and their social relations within it are important elements (e.g., their positioning in research institutes of governments managing the fisheries, or as experts working for the fishing industry or NGOs). What is apparent from our analysis is that the human dimension intersects with all of the topics and themes explored here such that this separate section on the human dimensions is somewhat redundant. That is telling and emphasizes how human dimensions are increasingly viewed as fundamental to contemporary fisheries research and management. We therefore conclude that the human dimensions will indeed be considered as an integral element of fisheries in the near future, providing insights and benefits for fisheries science more broadly (see McKinley et al. 2022). Yet, it also needs to be treated as a unique cross-cutting issue in its own right that needs to be addressed. We submit that better integration of biological and social science theories and practices is needed to manage fisheries in an holistic manner.

Rethinking governance, policy, and compliance

Ensuring the protection of fishers and fish value chain workers (e.g., through safety at sea and on land, social security, social development, and secured human rights) has been and continues to be one of the greatest challenges for the fisheries governance and policy framework (Papanicolopulu 2018; Nakamura 2022). For at-sea work, only 20 States have ratified the International Labour Organization Work in Fishing Convention 2007, hindering a stronger support for the international protection of decent working conditions in fisheries. While there have been some important international legal developments, as outlined above, through the adoption of non-binding instruments embedded on an ecosystem approach to fisheries management and, more recently following the human rights-based approach, there remain challenges in ensuring implementation of these instruments at the national level. Fisheries, especially small-scale fisheries, are not a priority to most governments' agenda. Fisheries is a marginalized sector (Purcell and Pomeroy 2015; Chuenpagdee and Jentoft 2011). As such, relying on political will and action to effectively implement policies and legislation should not be the only alternative.

Rethinking governance can begin through a more proactive work of non-state actors and broader inclusion of value chain activities, taking due account of a broader interest in implementing fisheries and fisheries-related policy and laws for the benefit of the wider fisheries community. These initiatives can support tracking the progress on the implementation of international instruments (Lynch et al. 2020). Through transdisciplinary research, for instance, fisheries scientists and legal researchers can work together to identify key issues in international instruments relevant to fisheries in countries' legislation and policies, highlight the gaps and needs for review and update (Nakamura et al. 2021). In certain countries, the recognition of customary fishing rights may not be spelled out in legislation or policy, but may be granted by national judicial courts, performing judicial activism (e.g., South Africa, Sowman and Sunde 2021; New Zealand, Cantzler 2022). It is also crucial to clarify opportunities for mutual supportive interpretation and application of human rights law and fisheries law to support the recognition and protection of rights of fishers working in rural and coastal areas (Morgera and Nakamura 2022).

All these approaches, however, take for granted the centrality of the fishing node of the value chain, which is only part of the fisheries sector. Indeed, the post-harvest node employs more than twice as many people (World Bank, FAO, WorldFish, 2012), but their needs are not considered in governance (see Barclay et al. 2022 for an example in tuna fisheries). New approaches must find ways to include value chain impacts and consequences in the governance systems. The impacts and influences are already acting, but in hidden and non-transparent ways, such as through market demand, private sector company policies, and social and political hierarchies.

A recent important development for the global fisheries was the adoption of the Agreement on Fisheries Subsidies by the members of the World Trade Organization, after decades of negotiation, but, as commentators note, some unfinished business (e.g., prohibition of subsidies that contribute to overcapacity and overfishing, and the differentiated treatment and permanent exemptions for small-scale fishing) were left for future negotiations (Tipping and Irschlinger 2022; Switzer and Lennan 2022).

Innovative ways to govern fishing have been largely pushed forward through the adoption of an ecosystem approach to fisheries management or ecosystem-based fisheries management. This approach has also been developed in international instruments (e.g., Reykjavik Declaration 2001) and technical guidance provided by FAO to supplement the CCRF (FAO 2003) and on legislating for an ecosystem approach to fisheries management (FAO 2016; FAO 2021). Several national bodies are adopting ecosystem-based fisheries management as a major policy shift in how fisheries are governed. The need for holistic ways of managing and governing fisheries stem from many reasons, but internationally from growing evidence of the ecological connectivity between transboundary fisheries resources and impact diverse ecosystems, biodiversity, and habitats, and which are impacted by multiple stressors, including climate change (Pinsky et al. 2018; Popova et al. 2019; Palacios-Abrantes et al. 2020).

The emphasis on the ecosystem approach continues to broaden the scope of fisheries and other sectors included in national and international fisheries policies and sustainable development agendas. Transitioning to these modes of governance, which seek to sustainably develop, require participatory decision-making that takes special account of affected and marginalized groups (Cohen et al. 2019). In this process, local communities can also contribute to improve the knowledge-base informing fisheries management measures and monitoring (Dias et al. 2020). However, the implementation of national fisheries policies, aside from those that enable trade, continues to substantially lag behind the drafting and adoption process, yielding well-intentioned fisheries management plans that are not fully executed and leading to unsustainable fisheries policies (e.g., Pelicice et al. 2017). This expansion has also included greater consideration of the contributions and potential impacts of various measures on small-scale fisheries, recreational fisheries, coastal and inland communities, and tropical regions (particularly in developing countries), with variable success. The representation of non-state actor participation in global fisheries institutions, such as regional fisheries management organizations, also continues to be selective (Petersson 2019).

Additionally, transboundary fisheries management continues to have ongoing and emerging challenges that will require enhancements to multi-national co-management and multi-sectoral coordination to promote sustainability and greater consideration of cumulative impacts in a changing climate (Popova et al. 2019). Efforts are required on multiple levels of national and international government cooperation to improve the legal frameworks and arrangements for strengthening monitoring, surveillance, and compliance (MCS) that address fishing in Areas Beyond National Jurisdiction and enhance Biological Diversity Areas Beyond National Jurisdiction negotiations, reduce IUU fishing, and further tackle the governance challenges for highly migratory species (Le Gallic and Cox 2006; Ardron et al. 2014; Petrossian 2014; Doumbouya et al. 2017, Popova et al. 2019). Improvements may include (a) developing economically viable monitoring, surveillance, and compliance plans and monitoring systems (e.g., Aloysius et al. 2019) that are fully incorporated into fisheries management planning, (b) improving monitoring compliance by supporting the capacity of authorized officers to perform their monitoring, surveillance, and compliance and enforcement functions, and establishing higher fines for non-compliance with applicable rules (Doumbouya et al. 2017), (c) adopting management measures with greater participatory monitoring and technological developments of more cost-effective systems that leverage AI and electronic monitoring systems, and (d) greater open access to fisheries data (e.g., Global Fishing Watch). Lastly, adaptive transboundary governance for a changing global ocean ecosystem is critical, particularly where shifts in target species distribution due to climate change are impacting fisheries, livelihoods, societies, and economies (Ojea et al. 2020). We submit that rethinking governance, policy, and compliance is necessary to achieve fisheries that benefit people while also protecting aquatic systems such that sustainable fisheries harvest is possible.

Achieving inclusion in fisheries, using the example of gender equity

A major thrust is needed to put equity and inclusion broadly on the fisheries agenda. In the preceding section, we used gender equity as an example of new approaches and issues but acknowledge that these issues extend to race, religion, caste, socio-economic status, Indigeneity, and beyond. Each one deserves more attention than we can provide here. The increasing commoditization of fisheries presents great challenges to sustainability and inclusion (Belton, Reardon and Zilberman, 2020). Whereas sustainability has received some attention through action by environmental NGOs, and even the large private sector interests, social inclusion has received little attention to date, with the exception of action to prevent the worst maltreatment of male crew in certain fisheries (HRAS 2019; ILO 2007). Even the attention given to social issues for male crew typically does not address the additional impacts and needs of the women in the affected fisheries households (Barclay et al. 2022). Furthermore, extending social inclusion to women throughout fish value chains would reveal an even wider set of social equity issues. Women make up about half of the workforce in fish value chains (FAO, 2022), but they are neglected in fisheries policy and action. Gender issues cannot be solved until issues in the political economy of fisheries are investigated and addressed (e.g., the extent of labour exploitation in processing and trading as well as fishing, the allocation of resource rights, investment and finances for women entrepreneurs, gendered trade impacts, and the political rights of different groups). Seen through a gender lens, these issues provide better understanding of the asymmetry of power occurring and the motivations and drivers of the value chain actors (Williams 2019).

Furthermore, women are not a homogeneous group with a single set of characteristics, needs, and interests. Gender research needs to take intersectional approaches to comprehend the complexities. Ferguson (2021), for example, used an intersectional approach in studying the beche de mer trade in Palau. Marital status and nationality (local and immigrant women and men) affected who benefited or was harmed. Men benefited most from international trade which affected the local stocks, from which local women and immigrant women benefited more than unmarried women and immigrant men.

The basic building blocks of achieving greater gender equality in fisheries are gender research carried out across appropriate scales and key intersectional factors, well-informed policies that are built on supporting and including gender and fisheries representatives in policy development, and sound gender-disaggregated data. As noted in answer to Question 1, gender-disaggregated data are scarce in fisheries. This problem hides the numbers of women involved, and their contributions and rights (or lack of); contributes to women's interests and knowledge being overlooked in fisheries management decision-making; and allows policy makers to ignore gendered differences in participation, needs and opportunities. Thus, as a basis for women's rights, fisheries lacks adequate data collections, and has few time series showing trends. Correcting this data gap is a major need for supporting gender equity.

Two gender issues in fisheries are often conflated, namely the professional presence of women in fisheries science, fisheries management and private sector positions, and the position of women workers in fish value chain nodes and research to illuminate it. Although the two are related in some respects, in others they share little in common.

Compared to 30 years ago, women are more numerous in professional positions in fisheries, such as fisheries scientists and management agencies, thus giving an impression of progress in gender equality in fisheries. The rise of women in the fisheries professional ranks, however, results from the gains in women's education and does not equate to progress more broadly in gender equality in fisheries value chains (Barclay et al. 2022). Professional women typically have to accept the workplace performance requirements and cultures that have prevailed from earlier times, although, in some situations, social media groups and professional associations are becoming active in overcoming gender discrimination in fisheries professional workplaces. The American Fisheries Society, for example, has a Diversity, Equity, and Inclusion Committee that focuses on professional concerns of recruiting and nurturing a diverse workforce more representative of the population with respect to women, race, ethnicity, sexual orientation, and abilities (Penaluna et al. 2017).

On the question of women's positions in fish value chains, and research on these, complex and different issues arise. Gender and fisheries research has grown slowly over the last 30 years (see Williams (2019) for a timeline of the efforts by researchers in the Asian Fisheries Society). In the last few years, serious gender research papers have started to appear in the top fisheries research journals when once most gender and fisheries scholarship was found in social science journals. The field is still small, however, and research funds are meagre and scattered. Few fisheries research agencies employ gender researchers, and fisheries management agencies likewise rarely hire experts with specialist gender knowledge. A survey of 65 countries found that only 25% of fisheries ministries had gender focal points responsible for coordinating responses to policies and mandates (and not necessarily gender experts) (Environment and Gender Index, 2015). Among environment ministries, only water ministries were less likely to have a gender focal point. Most gender research is undertaken in universities, and experts (researchers and technical experts) are contracted for specific tasks by mainstream fisheries agencies. Only the Asian Fisheries Society, among all the professional fisheries societies, has a formal gender section (the Gender in Aquaculture and Fisheries Section), focusing on research on women and gender equality in value chains (Williams 2019).

A small but growing number of networks have been formed supporting collective action by women working in fish value chains (Alonso-Población and Siar 2018), and also some activist groups working to sensitize the seafood industry to gender equality issues. Researchers often collaborate or are also members of these organizations, but the overall number is still modest. A few of the large international environment NGOs are taking a strong stand for gender equality in fisheries and we expect this trend to continue (e.g., Finkbeiner et al. 2021). Equity applies in many ways to fisheries yet has rarely been considered. Using gender equality as an example to indicate the needs for progress reveals a large set of tasks. Revising governance, management, and data systems to explicitly acknowledge, embrace, and celebrate equity, diversity, inclusion, and justice is sorely needed.

Understanding the role of fish as nutrition in a hungry world

Fish are clearly a source of food, although this is not always reflected in national policies. For example, only one in two public health nutrition strategies examined by Koehn et al. (2021) identified the importance of fish and shellfish consumption as a key objective. This is partially because the contribution of fish is often reduced to their protein provision, when in fact their role in addressing micronutrient deficiencies makes fish products a crucial part of a healthy diet (UN Nutrition 2021). There are also diverse perceptions between marine and inland fisheries in relation to their contribution to food security. While much more is known about the role of marine fisheries products in supporting food security (Golden et al. 2016), similar data are lacking for freshwater systems (Funge-Smith and Bennett 2019), even though the latter is particularly important in many food-deficit regions. For a long time, the disaggregated nature of fisheries data and their contribution to human diets made it very difficult to understand and properly value the role of fish in addressing food security challenges. Recently, Golden et al. (2021) modelled the nutritional properties of terrestrial foods and nearly 3,000 taxa of aquatic foods, and concluded that the top 7 categories of nutrient-rich animal-source foods are all aquatic foods, based on the benefits in terms of reducing micronutrient deficiencies, provision of omega-3 long-chain polyunsaturated fatty acids, and capacity to displace the consumption of less-healthy red and processed meats.

The tide is turning, and in food security circles there is a growing interest in "aquatic foods," as evidenced by the UN Blue Food Assessment (see theme section in the journal Nature https://www.nature.com/collections/fijabaiach/) and the outcomes of the 2021 UN Food Systems Summit. There are obvious reasons for this interest: aquatic foods are some of the more environmentally friendly food systems, and one that has significant potential for growth. After all, Africa produces only 2.5% of global aquaculture, and if protein and micronutrients must come from somewhere, fish will be a big part of the solution. However, present food systems still fail to recognize the diversity of aquatic foods, their potential to contribute to sustainable healthy diets, and their potential as a solution to address the "triple burden of malnutrition" (i.e., micronutrient deficiencies, undernutrition, and overweight and obesity) (FAO, 2020).

But promoting aquatic foods will require the engagement of many inside and outside the fisheries sectors, including interdisciplinary experts (e.g., supply chain, nutrition, processing, sustainability), realms (inland and marine), and diverse actors (from fishers to culturists to processors to consumers) from across the globe to realize their potential in a more sustainable, healthy, safe, and equitable manner, and in the face of external threats such as climate change (Nash et al. 2021; Tigchelaar et al. 2021). With almost 10% of the world's population suffering from undernourishment, there is no time to lose if we are to end hunger. Fish products benefit some of the most impoverished and food insecure peoples on the planet with much of that catch and consumption occurring within communities outside of any import/export systems. We are just now beginning to understand the many ways in which fisheries products from all realms contribute to nutritional security and thus benefit people around the globe.

Adapting to climate change

Climate change is modifying fish habitat and impacting fish populations and aquatic communities with effects observed from the cell to the ecosystem, this in turn is influencing human communities dependent on this ecosystem (Barange et al. 2018). Common stressors include changes in water temperature and ice conditions, changes in precipitation, alterations in river flows, sea-level rise, and ocean acidification (Paukert et al. 2021). Among other things, climate change had led to shifts in species distributions, with species moving to cooler areas by increasing latitude, moving offshore or occupying deeper waters (Cheung et al. 2013; Hobday and Pecl 2014). Climate driven shifts are not just associated with temperature but may also be influenced by changes in salinity, dissolved oxygen and pH, especially in estuarine and upwelling areas (Lauchlan and Nagelkerken 2018).

There is increasing need to consider these multi-stressor interactions which may impact physiological processes at the individual level subsequently impacting the population or species level through changes to recruitment, growth, size at maturity, and fecundity (Busch et al. 2016, Lauchlan and Nagelkerken 2020). Ecosystem effects through habitat change and food web dynamics also mean individual species cannot be considered in isolation. Understanding these broader potential impacts provides a means to select adaptation approaches, especially as the degree of environmental change and the formation of novel ecosystems (i.e., configurations not previously recorded) mean that historical observations are no longer always a reliable guide. Global ecosystem models are predicting a 5-15% drop in zooplankton and a 5-25% drop in global marine fish biomass even in the absence of fishing (Tittensor et al. 2021). Changed freshwater flows are likely to impact inland fisheries, too (van Vliet et al. 2013).

Under those circumstances, fisheries production would be likely to drop. Indeed, fisheries production has already declined, albeit not just attributed to climate change. Estimates have suggested global catch could reduce 6% by 2050 associated with ocean warming and changes in primary productivity (Cheung et al. 2016; Golden et al. 2016; Boyce et al. 2020). Further, such reductions are likely greater in tropical areas with predictions catches will decrease by 30% (Cheung et al. 2016). To ensure climate effects on fisheries production are not realised, it would be helpful for fisheries management to incorporate climate-resilient policies.

All of these environmental and production changes are associated with effects on the human communities using those resources (Colburn et al. 2016), but also challenge fisheries management processes. Traditional fisheries assessment and management approaches are based on an assumption of stationarity and climate change associated changes in productivity are creating issues around how to be suitably precautionary in years where extreme environmental conditions are influencing stock state (Dorn and Zador 2020) or where environmentally influenced tipping points exist (Möllmann et al. 2021), how to transparently handle regime shifts in productivity (Wayte 2013), how to deal with growing numbers of non-recovering stocks (Britten et al. 2017; Knuckey et al. 2018) and how to adjust reference points (Travers-Trolet et al. 2020). While some regions have sufficient data to undertake climate versus fisheries attribution exercises (Litzow et al 2021), this is not typical of many locations. Moreover, institutional inertia or past management decisions (such as the allocation of individual quota rights) can make agile switches in management approaches difficult, if not infeasible. Bryndum-Buchholz et al. (2021) review of fisheries management legislation and policy in 11 countries found that while most countries considered climate change in the decision-making process, no country had at that point incorporated climate change into stock assessments or mentioned it in policy/legislation.

While fisheries management policies, legislation, and approaches do not generally consider climate change as of yet, they can be modified or enhanced to be adaptive to climate change (Bryndum-Buchholz et al. 2021; Link et al. 2021). Ecosystem-based fisheries management, for example, can incorporate impacts associated with climate change through ecological risk assessments, ecosystem indicators (Link 2010; Hobday et al. 2011; Tam et al. 2017) and improved forecasting methods (Årthunet al. 2018). Stock assessment methods will require modification to account for and incorporate climate change (Plagányi et al. 2011; Punt et al. 2021) and governance systems should consider potential distributional shifts in fish stocks (Bryndum-Buchholz et al. 2021; Link et al. 2021). The governance and management parts of the entire fisheries system also need to and can insert this climate-related information (Link et al. 2021).

It is also not simply a matter of stock-based effects on fisheries, physical changes - such as lost infrastructure and reduced safety at sea (Sainsbury et al. 2018) - can result from climate change and are only just beginning to be addressed more openly in fisheries planning (e.g., vessel design, new port construction etc). Similar issues will arise around changed waterflow and environmental profiles for inland fisheries - e.g., extreme flooding can wash away any fixed infrastructure (Hoa et al. 2008) or directly affect fish stocks (Rytwinski et al. 2020).

One factor not widely considered is how climate change may impact nutrient supplies to freshwater, coastal, and marine systems. If extreme weather events become more common leading to increased runoff, then nutrients may be exported from land to rivers, estuaries and the sea thereby increasing nutrients in food webs (Hicks et al. 2019). For example, two critical micronutrients, zinc and calcium, are exported from soils during heavy rainfall in tropical areas. Food and nutrient policies will need to consider how climate change may alter nutrients, along with fisheries yield, as fisheries clearly have a role to play in providing the recommended dietary allowances for coastal populations, particularly in countries where nutrient intakes are inadequate (Golden et al. 2016; Hicks et al. 2019).

Increasing political awareness for healthy waters is a start. Nature-based solutions are being incorporated into climate change programs to protect and/or restore ecosystems mostly in coastal systems (Cohen-Shacham et al. 2016). Fisheries emit atmospheric CO_2 through landings, processing, and consumption (Mariani et al. 2020). Government subsidies also contribute to CO_2 production (among other issues; Sumaila et al. 2021) by allowing fisheries vessels to fish on the high seas. While a transition to renewable energy may occur in coming years and decades, it will take a considerable time to transition the global fleet. Moreover, it is important to consider the carbon stocks within fish themselves and the contributions they make to global cycles. Mariani et al. (2020) have recently investigated the ability of fish to sequester carbon after natural death demonstrating that fisheries have released 0.73 billion metric tons of CO_2 since the 1950s (albeit a rather small number relative to other sinks and sources). Removing fishing from unprofitable areas would lower CO_2 emissions as less fuel would be required. Rebuilding and maintaining productivity of fish stocks would increase biomass through increased numbers of fish including fish of larger size leading to increased carbon sequestration in both the short and long term (Mariani et al. 2020).

Climate mitigation and adaptation would therefore be expected through elimination of overfishing and setting up of protected areas. The latter has long been promoted as part of a global effort to address biodiversity loss, in addition to help deal with climate change. While many aspects of marine protected areas are much debated (such as in terms of size, location, effectiveness), and there is no doubt the form will need to be modified to allow for changing species distributions and ecosystem structures, there is a general consensus that communities will also need to be part of such a response, as protected areas have a higher rate of success when they are supported, and better yet initiated, by communities. Climate change and our response to it will in many ways define the future of fisheries and the communities that depend upon fish and healthy aquatic systems.

Embracing transdisciplinarity

Fisheries are tightly coupled social-ecological systems (Ommer and Perry, 2011) with complex interactions among ecosystems, human communities, and target species. The challenges facing fisheries thus span several academic disciplines, research topics, and sectors, and finding viable solutions requires integration across diverse disciplines and knowledge systems, and incorporation of perspectives from all interested user groups (i.e., rights holders, stakeholders, practitioners, managers, and decision-makers) (Turgeon et al., 2018; Chuenpagdee & Jentoft, 2019; Barnes et al., 2021). As progress has been made toward centering the human dimensions in fisheries research, multi-, inter-, and transdisciplinary methodologies have also evolved (see McKinley et al. 2022). Although these approaches all have merit, transdisciplinary frameworks extend beyond multi- and inter-disciplinary approaches to include and collaborate with non-academic actors, and thus require inclusive and cooperative practices that typically involve partnerships and knowledge exchange across science, policy, practitioner, stakeholder, and governance boundaries (Turgeon et al., 2018; Kelly et al., 2019; Barnes et al., 2021).

Transdisciplinary approaches can enable researchers and managers to understand a broader range of complex problems facing fisheries, as well as solutions to these challenges (Jentoft and Chuenpagdee, 2009). For example, understanding compliance behaviours in relation to management (Fulton 2021) or preparing fishing societies to adapt to climate change and other anthropogenic perturbations (Bennett et al. 2016; Bryndum-Buchholz et al. 2021; Paukert et al. 2021; Syddall, et al., 2021) would be fruitful. Moreover, there is scope for improving communication between disparate but interconnected groups including the users of new technologies, fisheries modelers, fisheries managers (Degnbol et al. 2005), and/or economists, ecologists, and social scientists (Bennett 2019). Transdisciplinarity often necessitates co-production, which can inform more integrated and human-centered approaches to unite ecological concerns with management, community perspectives and preferences, as well as human behaviours (Fulton et al. 2014).

Integrating diverse sectoral representation on a research team from beginning (i.e., question development) to end (i.e., communicating findings) can help ensure that the knowledge produced is inclusive, salient, credible, and practical (Cash et al. 2002). For example, co-producing policy-oriented research with community representatives increases the likelihood that communities will be willing to abide by fishery regulations (Karr et al. 2017). Input from fisheries managers or practitioners can help to create appropriate fisheries protections and implement climate adaptation programs (Bennett et al.

2016). Including government decision makers on the team improves knowledge transfer at the science policy interface and ensures that the knowledge produced will be useful in practice (Cvitanovic et al. 2015).

Transdisciplinary work is challenging and time-consuming. For example, researchers must become more open to working across diverse disciplinary 'languages' (Andrews et al. 2020) and learn to communicate with diverse partners (Macher et al. 2021; Evans and Cvitanovic 2018; Kelly et al. 2019). Despite widespread acceptance of transdisciplinary approaches to fisheries research and management there are still barriers in personal and institutional capacity to carry out 'good' transdisciplinary research (Nyboer et al., this issue). The need for support in inter- and transdisciplinary science is especially critical at early-career levels (Kelly et al. 2019), where limited training opportunities in transdisciplinary skills, institutional inertia, as well as competitive funding pools, and limited access to partners all constitute barriers to engaging in transdisciplinary approaches (Kelly et al. 2019, Nyboer et al. this issue). Moreover, while expanding the capacity of individual researchers helps, engaging dedicated specialists (such as knowledge brokers) is also important because the skill sets required; doing the science, communicating well across audiences, and understanding the different cultural forms of communication can be beyond what an individual alone can achieve. Wise creation of cross-supporting teams is an effective means of gaining depth and breadth (Kelly et al. 2019). Efforts to achieve transdisciplinarity have the potential to transform how we understand and manage fisheries for the benefit of all, now and into the future.

Respecting Indigenous knowledge systems

For millennia, Indigenous peoples used and managed aquatic resources around the globe in a sustainable manner (e.g., Gadgil et al. 1993; Atlas et al. 2021). Underpinning these efforts were deep relationships between people, place, water, and animal life and a recognition of their interconnectedness (Reid et al. 2021). Over the past few centuries Indigenous Peoples and rights holders have been marginalized or even been subjected to genocide. The great wisdom and knowledge that was developed through spending time on the land and water and shared (i.e., passed along) by elders and other knowledge holders through teachings, stories, art, and cultural practices (e.g., ceremony, spirituality) was co-opted, ignored or destroyed by colonial governments (e.g., to enable exploitation). Only in the last decade or so has attention been paid to the immense value of Indigenous knowledge systems and recognition that such knowledge can be used in tandem with western knowledge systems (i.e., science). This does not require abandoning western science but rather adopting a two-eyed seeing approach. Two-eyed seeing is "learning to see from one eye with the strengths of Indigenous knowledges and ways of knowing, and from the other eye with the strengths of mainstream knowledges and ways of knowing, and to use both these eyes together, for the benefit of all" (Bartlett et al. 2012; Reid et al. 2021).

Rethinking relationships with Indigenous communities and developing co-management systems that empower Indigenous communities and governments and give them sovereignty over fisheries resources are sorely needed (Wong et al. 2020). Moreover, there is a need to train western scientists and managers on how to respectfully engage with Indigenous communities, respect their knowledge and bridge knowledge systems given current reliance on western science (Kadykalo et al. 2021). There are a growing number of examples of co-production and co-assessment that involve Indigenous community members in fisheries monitoring and management which is promising (Crook et al. 2016; Chapman and Schott 2020). Recognizing some of the ongoing failures of current fisheries management systems combined with the need for reconciliation, there is opportunity and need to bridge knowledge systems (Plagányi et al. 2013; Fache and Pauwels 2020; Alexander et al. 2021) and empower and enable Indigenous communities to resume their role as guardians of aquatic resources (Fischer et al. 2022). Embracing the UN Declaration on the Rights of Indigenous Peoples (https://www.un.org/development/desa/indigenouspeoples/declaration-on-the-rights-of-indigenous-peoples.html) and developing meaningful and respectful partnerships with Indigenous rights holders is not only a legal and ethical imperative, but one that will benefit aquatic resources. Time and effort must be given to develop meaningful partnerships and relationships with Indigenous knowledge holders and rights holders - and to support Indigenous groups to identify shared fisheries and aquatic ecosystem goals and to envision and achieve sustainable management systems that are just.

Thinking ahead with foresight science

Conceiving and achieving sustainable fisheries into the future demands the use of forward-looking thinking, tools, and approaches that can enable diverse stakeholders (including researchers and managers) to proactively prepare for and respond to dynamic fisheries futures (Nash et al. 2021). Such approaches are sorely needed given the already crowded inshore and inland waters and the new and expanding uses of offshore aquatic ecosystems related to energy development, shipping, tourism, offshore port facilities, cables, pipelines, mining and so on that need to be balanced with fisheries activities. Foresighting – a process of creatively identifying possible, plausible, alternative futures in the medium to long term – is one approach that is potentially useful for fisheries management and planning (e.g., Martin 1995, Burgelman et al. 2014, Magness et al. 2021; Kelly et al. 2022) as well as broader management of aquatic systems. Most typically, foresighting exercises combine different methods and tools (e.g., horizon scanning, scenario development, model simulations) to create scenarios or visions that describe and/or compare possible futures (Popper 2008).

As outlined above, transformative changes are needed to address key fisheries challenges now and into the future. Foresighting presents a means to envision multiple fisheries futures, which can be used to inform efforts and alternative pathways to sustainability (Kelly et al. 2022). For example, by engaging stakeholders in imagining potential alternative futures, and proactively thinking and acting in preparation for these futures (McDonald et al. 2019). Thus, foresighting can foster and enable innovation – that emerges through dialogue, collaboration, and interaction between different preferences, perspectives, and ways of thinking about the future. Critical to this, will be identifying and recognising a wider range of knowledge (e.g., Fischer et al. 2022) and extending opportunities to participate to enable diverse stakeholders to engage and contribute. Foresighting exercises that involve diverse teams of stakeholders encourage inclusivity, transparency, and the resulting legitimacy of the possible fisheries futures imagined and conceived (Amanatidou 2014; Tatar et al. 2020). It is time to embrace foresight science to envision and potentially shape fisheries futures, including reducing uncertainty and preparing for managing fisheries in a dynamic world and as part of integrated multi-sector management.

Working together across scales

The issues discussed above are relevant from the smallest scales of relevance to fisheries (e.g., the genome of individual fish) through to considerations at the levels of entire stocks, ecosystems, national fisheries, and interconnected systems that span jurisdictions either regionally (e.g., those under the auspices of a regional fisheries management organization) or even globally (in the context of climate change of global trade systems). Looking forward requires science and knowledge sharing that can connect across scales. This does not necessarily mean all fisheries science must intentionally span multiple scales. However, it does mean that fisheries scientists should expect to find collaborators or other interested parties may want to connect their science into larger knowledge networks. In addition, there will be the expectation of more transparent knowledge sharing and potentially the expectation of more rapid acquisition and dissemination of information. These linkages and expectations will require technological advancements not only to facilitate it in the first instance but also to make sure such advancements can draw on and benefit the lived experience of fisheries of all backgrounds (FAO 2019). Technology and the ability to rapidly aggregate and integrate complex data and information sources to inform fisheries assessment and management has the potential to make fisheries management more responsive and dynamic (Cooke et al. 2022). Attitudinal openness to collaborations and information sources not typically associated with formal fisheries management will also be necessary (Fulton 2021). Fisheries management is complex and demands assessment schemes and management strategies that extend across diverse scales.

Conclusion

Here, we provide a retrospective perspective on our successes and failures in fisheries from the past 30 years coinciding with the timeline since the first WFC was held (1992). We also provide a prospective perspective on what is needed to achieve and sustain vibrant fish populations and sustainable fisheries in the coming 30 years that benefit current and future generations (Figure 1). The importance of the WFC in helping to shape research agendas and identify innovative management opportunities cannot be understated. Previous syntheses and proceedings have served as guideposts for our community as we work collaboratively to address challenges that connect people, places, and fish. For example, Chuenpagdee and Bundy (2005, 2006) provided a thought-provoking synthesis of ideas emerging from the fourth WFC held in Vancouver, Canada in 2004 that highlighted the intersection of different knowledge domains.

Much has changed since the first WFC in Athens in 1992. We have certainly made progress on key issues - including bycatch, ecosystem-based management, and governance (and less so on others like the social dimensions of fisheries and equity). Yet, our human population continues to expand along with increasing inequitable consumption of resources. The continued use of unsustainable practices and a growing number of additive/synergistic effects arising from various threats make the future of fish populations and fisheries uncertain. Moreover, we sit in a period of reconciliation where we attempt to ensure that fisheries are just, equitable, and inclusive with benefits shared amongst all. It is our hope that the ideas shared here, particularly those focused on what is needed for the next 30 years, will help to empower existing fisheries professionals and inspire the next generation of fisheries professionals (see Nyboer et al. 2022) and, frankly, anyone associated and interested in fisheries from fishers to managers to scientists to act. At future WFC meetings, we will be able to assess progress towards the goal of sustaining vibrant fish populations and sustainable fisheries that benefit all while refining our path based on input from those with interest and expertise in fisheries science, management, and stewardship. Doing so will not only ensure a future for fish but also for those who depend on them for nutrition, livelihoods, and culture.

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Figure 1. Achieving sustainable and vibrant fish populations and fisheries.