

Valuing and understanding fish populations in the Anthropocene: key questions to address

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Research on the values of fish populations and fisheries has primarily focused on bio-economic aspects; a more nuanced and multidimensional perspective is mostly neglected. Although a range of social aspects is increasingly being considered in fisheries research, there is still no clear understanding as to how to include these additional values within management policies nor is there a cogent appreciation of the major knowledge gaps that should be tackled by future research.

This paper results from a workshop held during the 50th anniversary symposium of the Fisheries Society of the British Isles at the University of Exeter, UK, in July 2017. Here, we aim to highlight the current knowledge gaps on the values of fish populations and fisheries thus directing future research. To this end, we present eight questions that are deeply relevant to understanding the values of fish populations and fisheries. These can be applied to all habitats and fisheries, including freshwater, estuarine and marine.

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INTRODUCTION

The definition of value is usefully stated as ‘the worth, desirability, or utility of a thing’ (OCED, 1996). Marine biologists and fisheries scientists take as a given that fish are valuable in these senses and may consequently assume that fish populations are valued. It could be said that valuing fish populations is a prerequisite for effective and sustainable management of those populations, whether for fisheries or conservation (Vucetich *et al.*, 2015). Therefore, understanding the ways and extent to which fish populations are valued both by stakeholders and society, generally, is fundamental to engaging these groups in meaningful and effective discussions around future fish and fisheries management. An assumption, however, that fish populations are valued by the public at large, either commercially or for other reasons, is not certain (Hargrove, 1992; FoF, 2017). It is obvious that commercially important species are valued in an economic sense, but in order to manage fish populations successfully we need to consider carefully the nuances of what is meant by value in a broader context. This becomes even more important with the recognition of detectable human influence on the earth system in the recent past, encapsulated in the concept of the Anthropocene epoch (Lewis & Maslin, 2015; Maslin & Lewis, 2015). This will inevitably impinge on fish populations as well as our understanding of fisheries and even their role in national economies (Allison *et al.*, 2009), through changes in, for example, sea surface temperature (Genner *et al.*, 2004; Magurran *et al.*, 2015).

It is suggested that in order to manage and conserve fish populations in the face of anthropogenic changes, we need to understand better the ways fish are considered to be valuable. Such understanding can then underpin communication between the various stakeholders and society more generally, so as to facilitate implementation of improved management tools to meet future challenges. In moving beyond purely economic considerations of value, it is necessary to explore other perspectives of what constitutes value, in terms of importance and usefulness. To this end, this paper attempts to identify key questions to aid this process, divided into those relating to gaps in understanding of what constitutes value in relation to fish populations and those relating to issues of implementation once improved understanding is developed.

We can consider the ways in which fish populations possess value through five main areas: economic, ecological, human health, cultural and recreational. There is already a considerable literature on ecological value in terms of the roles of species in ecosystems and the consequences of changes in their distribution and abundance (Costanza *et al.*, 1997; Holmlund & Hammer, 1999; Barbier *et al.*, 2011). The extent to which such ecocentric and intrinsic values inform the management process, however, is less explicit. There is also substantial research on the monetary harvest value of fished populations (Dyck & Sumaila, 2010), but there is little cross-talk between these definitions of value. Some progress on the ecological front has been made through development of the ecosystem approach to fisheries management (Pikitch *et al.*, 2004; Beard *et al.*, 2011), but other elements relating to fish and fisheries values, often very significant to fishing communities, have rarely been explored (Close *et al.*, 2002; Chan *et al.*, 2012).

The complexities of the concept of valuing fish populations by various human groups have been framed above in the context of effective management. The idea of management of fish populations, however, is itself a fragile one. In most cases, it is not fish populations that are managed directly, but rather factors influencing those populations.

For instance, commercially exploited species are usually managed through intervention in the mechanics of the fishery (*i.e.* the opportunity to fish and the tools used to do so) rather than the fish population directly. There are examples of direct management, such as stocking of hatchery fish, or culling of undesirable species, but the efficacy of such measures is often open to question and very few natural habitats are amenable to such manipulations.

If we are to achieve the desirable goal of managing fish populations sustainably for both commercial exploitation and conservation, we must not only address key issues required to clearly understand the range of meanings of both valuing and effective management across a wide range of stakeholders, but must also identify mechanisms by which to implement effectively this knowledge as widely as possible.

METHODS

During the 50th anniversary meeting of the Fisheries Society of the British Isles at the University of Exeter, U.K., in July 2017, several workshops tackling different topics related to fish populations were held. During one of these workshops, 15 people including the authors discussed values of fish populations. This paper is the result of this workshop. Many questions were raised from this discussion, the list was refined through subsequent online discussion and the core questions that are thought to be highly significant in the near future became the focus of this article.

To address these questions and the overall goal of improving our understanding of what is necessary to reach sustainable management of fish populations, this paper has been structured in two parts: the first four questions focus on defining different aspects of the values of fish populations and fisheries, whereas the latter four questions highlight the need of including these values in the management of these resources (Table I).

FISH POPULATIONS AND FISHERIES VALUES

QUESTION 1: BEYOND ECOSYSTEM SERVICES: WHAT ARE THE ECOCENTRIC VALUES OF FISHES?

Fish and fisheries worldwide, including those in marine, estuarine and freshwater environments, have a range of values to people, which vary in their quantification due to the wide array of interests, incomplete understanding and the lack of a single all-encompassing measure of value. Food provision is the greatest single economic value of fisheries representing 88% of approximately 167 Mt. of fish produced in 2014 (FAO, 2016). Quantifying the value of fish and fisheries beyond simple economics is more challenging. Cultural ecosystem services (*i.e.* recreational fishing), particularly spiritual benefits (*i.e.* aesthetics) (Sarukhán & Whyte, 2005), are especially difficult to quantify, but appreciation of this type of service is increasing (Sandifer *et al.*, 2015). All of these values are of direct utility to humans; hence, philosophers call these utilitarian, instrumental, or anthropocentric values (Callicott, 2006). In contrast, intrinsic or ecocentric values are those that are centred on animals, plants, species or ecosystems, irrespective of human presence or preference (Rolston, 2012).

TABLE I. Summary of the eight key questions presented in this paper and suggested future steps towards their resolution

Questions		Key tasks for the future
Question 1	Beyond ecosystem services: what are the ecocentric values of fishes?	i. Understanding the socio-ecological dynamics of fisheries and fish populations; ii. Assessing the interaction and possible future impacts of these dynamics on socio-economics; iii. Furthering research and education on the importance of fish populations for the services they provide humans; iv. Future efforts should also be directed towards improving the dialogue of ecocentric valuation of fishes;
Question 2	Why should we value the link between fisheries or wild fish populations and human well-being?	i. Describing the specific relationship between fisheries and human well-being; ii. Presenting this relation as a value of the fishery given in financial terms;
Question 3	What is the value of recreational fishing?	i. Understanding the socio-ecological drivers of change at different scales; ii. Accounting for the social factors that might influence recreational fisheries resilience and adaptive capacity;
Question 4	What is the value of the fish we trade for consumption?	i. Guaranteeing an appropriate management of valuable seafood commodities traded between poorer and richer countries; ii. Ensuring that the value chain is fairly distributed across the supply network; iii. Establishing a standardized approach to recording and logging trade data that leaves no ambiguity; iv. Fostering collaborative approaches to governance and enforcement so that fraudulent behaviour is identified and punished, while approved good practice is encouraged and rewarded;
Question 5	What are the gaps in involvement and representation of women in valuing and managing fish and fisheries?	i. Highlighting the continuing disparities in equality regarding valuing and managing fish populations; ii. Ensuring outreach and inclusion of women in all capacities in all future research surrounding fisheries;
Question 6	How can we work towards equitable access to fisheries resources, particularly for developing nations?	i. Ensure the developmental gap is bridged at this scale; ii. Five considerations to direct and indirect access; iii. Establish equity as a key goal in the largest, open access resource in the world

TABLE I. Continued

Questions	Key tasks for the future
Question 7 Why is it important to recognize and safeguard genetic diversity of wild fishes (and how can genomics help)?	i. Integrative connectivity and population structure assessments to refine existing fisheries management units and define units in newly developing fisheries (<i>e.g.</i> deep-sea and polar fisheries) to avoid loss of unrecognized diversity; ii. Regular and standardized monitoring of standing genetic variation and adaptive diversity in key species and beyond for early detection of and differentiation between signs of depletion, induced evolution, and response to environmental change; iii. Investigating and monitoring how relocation, stock enhancement, and genetic rescue help management without compromising genetic diversity; iv. Regular and comprehensible communication efforts between scientists, stakeholders and managers
Question 8 How can the value of scientific research be increased through informing fish populations and fisheries management?	i. Providing evidence to governments to inform policy; ii. Working alongside a boundary organization; iii. Communicating your scientific research to non-specialist audience;

Ecocentric values have been known to many human cultures throughout history; indigenous peoples throughout the world hold various worldviews that assign intrinsic value to animals and plants, for example. Only during the past 50 years, however, has western science given much thought to ecocentric valuation. With the growth of the disciplines of environmental ethics and conservation biology, ecocentric valuation and intrinsic natural value came into focus (Rolston III, 1975; Callicott, 1989). Soulé (1985) counted intrinsic natural value among the normative postulates of conservation biology and today the first organizational value of the Society for Conservation Biology (SCB, 2017) states: ‘There is intrinsic value in the natural diversity of organisms, the complexity of ecological systems and the resilience created by evolutionary processes.’

Philosophers have developed various theoretical frameworks for ecocentric valuation; foremost among these have been those of J. B. Callicott and H. Rolston III (Kawall, 2017). Both of these frameworks are centred on what is termed an eco-evolutionary worldview. An eco-evolutionary ethic recognizes that although humans may be the sole species capable of moral reflection, we are not the sole species of moral worth; hence, we have moral duties towards other species and ecosystems (Rolston, 2012; Piccolo, 2017). Over 500 prominent scientists, philosophers and conservationists have recently added their signatures to a statement of support for ecocentrism (Washington *et al.*, 2017), lending credence to the view that

ecocentric valuation holds an important place in developing a rationale for nature conservation.

Considering this, we believe that in the future, it is key to focus on understanding the socio-ecological dynamics of fisheries and fish populations, assessing the interaction and possible future consequences of these dynamics on socio-economics and furthering research and education on the importance of fish populations for the services they provide humans.

QUESTION 2: WHAT IS THE RELATION BETWEEN HUMAN WELL-BEING AND THE CONTACT WITH WILD FISH POPULATIONS?

There is much research suggesting that exposure to nature can improve feelings of positive emotion, reduce stress and increase cognitive fascination (Ulrich, 1984; van den Berg *et al.*, 2003; Velarde *et al.*, 2007; Bowler *et al.*, 2010). We value the ocean; there are thousands of scuba divers (PADI, 2015), approximately 2.1 million operational fishing boats worldwide (FAO, 2008) and approximately 40% of the world's population lives within 100 km of the coast (CIESIN, 2012). Therefore, it is essential to understand how fishes and fisheries affect our mental health and use this information to improve understanding of the value of fishes and fisheries beyond their direct commercial value.

There are some important considerations which fisheries managers and those that value fishes need to take into account. For example, what is the value of the cognitive fascination children feel when they feed fish from a bridge? What is the value on mental health of a scuba diver diving in an area of high biodiversity? What is the worth of fishing communities' well-being when considering fisheries management? It is already known that the mood of people can be increased when they are exposed to greater levels of aquatic biota (Cracknell *et al.*, 2016). Recent research has proved that commercial fishers may have very poor levels of mental health, which is mostly attributed to modern day pressures such as changeable policy (King *et al.*, 2015). Changeable policy is linked to fisheries considered as being unsustainable. If fisheries were at sustainable levels, management would not need to be as variable and would thus improve fisher mental health. This would increase the value of the fishery to the stakeholders and their wider communities.

There are existing studies that document how greater actual or perceived species richness is linked to improved mental health, although the majority of these are terrestrial (Fuller *et al.*, 2007; Luck *et al.*, 2011; Dallimer *et al.*, 2012). There is currently little research regarding mental health and well-being with aquatic environments (Sandifer *et al.*, 2015). Therefore, research is needed to shed light upon the specific relationship between fisheries and human well-being and to present this relation as a value of the fishery given in concrete, quantifiable terms. This question should be applied to developed and developing communities, as well as recreational and commercial sea-users.

QUESTION 3: WHAT IS THE VALUE OF RECREATIONAL FISHING?

The general lack of regulation, monitoring, quantitative participation data and harvest statistics significantly hampers our ability to understand the full significance of recreational fisheries (Pauly & Zeller, 2016). There are some indications that recreational

activities may have become a global conservation concern (Post *et al.*, 2002; Cooke & Cowx, 2004). Thus, a conversation on assessing the values of fish populations in the context of sustainability should explicitly include recreational fisheries.

Recreational fishing is defined as 'fishing of aquatic animals that do not constitute the individual's primary resource to meet basic nutritional needs and are not generally sold or otherwise traded on markets' (FAO, 2012a), although other definitions have been provided (Arlinghaus & Cooke, 2009). Despite its leisure nature, recreational fishing often overlaps with the extraction of catch for domestic consumption (Cowx, 2002) and this can be worrying when participation in recreational angling activities is high, (up to 10% of the total population in the industrialized world (Arlinghaus *et al.*, 2015)). It must also be highlighted that while commercial fisheries mainly target the marine environment, recreational fisheries have access to most of the world's freshwater and inshore marine environments which can act as important habitats for certain life stages of fish (juvenile, spawning, feeding) making them vulnerable to over-exploitation (Cooke *et al.*, 2002). Recreational fishing harvest can also be higher than expected, with marine recreational fisheries in the U.S.A. thought to account for 10% of total fish landings (Coleman *et al.*, 2004).

It is well documented that recreational fisheries have high socio-economic and socio-cultural importance, providing many benefits to society although these can be difficult to quantify and evaluate (Arlinghaus *et al.*, 2002; Pitcher & Hollingworth, 2008). One major benefit of recreational activities is economic: 58 million marine recreational anglers worldwide annually generate U.S. \$39.7 billion in expenditures and support almost 100 000 jobs (Cisneros-Montemayor & Sumaila, 2010). Other important social and ecological benefits include improved quality of life for recreational anglers and support for recreational fisheries management which often include ecosystem level conservation efforts with substantial environmental benefits (Arlinghaus & Cooke, 2009). Indeed, the sustainable management of recreational activities is seen as increasingly important for natural capital worldwide (Ghermandi & Nunes, 2013).

The main issues facing recreational fishing have been widely documented (Cooke & Cowx, 2006; Lewin *et al.*, 2006; Arlinghaus & Cooke, 2009; Winfield, 2016) and include: exploitation through anthropogenic mortality; selective exploitation with respect to species, size, age, sex or behavioural and physiological traits; harvest during a critical life stage; sub-lethal effects such as wounds from catch and release or unplanned release; pollution and environmental disturbance; stocking and introductions of unfit, or non-native, invasive strains or species. Furthermore, the likely effects of climate change, such as increased water temperatures, decreased dissolved oxygen, increased eutrophication, food-web and habitat alterations, are also likely to affect the future of recreational fishing, especially in fresh waters (Ficke *et al.*, 2007). For marine fisheries, climate change is likely to result in shifts in abundance and distribution of fish fauna as a mechanism of coping with increasing temperatures (Last *et al.*, 2011). All these combined effects will affect fish populations in general and will therefore be relevant to both commercial and recreational fisheries, indicating that considerations on value and sustainability should not treat activities in isolation.

With environmental and anthropogenic pressures affecting recreational fisheries, we believe that it is key to focus future research on understanding the dynamic socio-ecological drivers of change at different scales and accounting for the social

factors that might have an influence on recreational fisheries resilience and adaptive capacity.

QUESTION 4: WHAT IS THE VALUE OF THE FISH THAT WE TRADE FOR CONSUMPTION?

Thousands of fish species are regularly harvested as a food source in every aquatic habitat on the planet and hundreds of them are commonly traded globally to meet the demand of growing human populations and to generate income. Only a small fraction of these species are being studied to an extent that allows reliable estimation of their stock and conservation status, their ability to respond to exploitation regimes and the effect that harvesting has on their broader ecosystem. Some species sustain small-scale fisheries that provide livelihoods and protein sources to local communities, while others are harvested in one part of the world and go through a long and complex chain of processing and trade, which often entails several countries (Watson *et al.*, 2016). Understanding and monitoring this complex seafood trade network is essential to guarantee sustainable exploitation and compliance with global conservation targets [*e.g.* Convention on Biological Diversity, 2001, among others].

A significant proportion of fish species harvested in the Global South (*i.e.* Africa, Latin America, and the developing countries in Asia), is processed and shipped to wealthier countries at a premium, which makes such a supply chain financially viable; yet, the more complex the trade, the greater the opportunity for fraudulent operations, such as the misnaming and misreporting of fish species and the entrance of illegal catches into the market (Cawthorn & Mariani, 2017). The value chain added through these practices only benefits few actors at some nodes of the trade network, while escalating damaging consequences on natural resources (Pramod *et al.*, 2014).

In practice, the seafood trade will continue to have a strong global component, particularly considering the rapid rise of aquaculture and the logistic improvement afforded by technology. Nevertheless, it is paramount to maximize cooperation among producing–exporting–importing countries, towards a key set of tasks that will maximize long-term value of wild fish populations and their responsible management (MSC, 2017). Among these we highlight: efforts to guarantee that valuable seafood commodities traded between poorer and richer countries are appropriately assessed and managed; ensuring that the value chain is fairly distributed across the supply network; establishing a standardized approach to recording and logging trade data that leaves no ambiguity as to the species harvested, their area of origin and their trade flow; fostering collaborative approaches to governance and enforcement, so that fraudulent behaviour is consistently identified and punished, while approved good practice is encouraged and rewarded.

FISH POPULATIONS AND FISHERIES MANAGEMENT

QUESTION 5: HOW CAN WE WORK TOWARDS EQUITABLE ACCESS TO FISHERIES RESOURCES, PARTICULARLY FOR DEVELOPING NATIONS?

Cochrane (2000) highlights a failure in our primary considerations in fisheries management: sustainable utilization, economic efficiency and equity in access to resources.

Arguably, in 2017, this remains particularly true for the last of these. Small-scale fishers of developing nations remain routinely marginalized and their low rents but high food security and employment contributions are afforded low value in a globalized, politically motivated system which encourages rapid technological growth and urbanization of labour (Cochrane, 2000; Béné *et al.*, 2010). Consequences include the sale of large swathes of fishing rights to developed nations (*e.g.* in East Africa), valuing short-term financial gains over long-term human development (Binet & Failler, 2011).

Fundamental to equitable access for those reliant on these small-scale fisheries is the development of mechanisms that incorporate social equity and wellbeing in fisheries (Coulthard *et al.*, 2011). Some progress has been made through critical FAO policies (FAO, 2015) which address marine tenure rights, decentralize management to local people and address issues of management capacity, equality between the sexes and market access. This has manifested as widespread adoption of co-management legislation, aiming to provide appropriate support to local people in decision-making and adaptive management. There is legitimate criticism of the governmental support offered in many cases (both financial and operational), however, with a heavy load currently borne by non-governmental organizations and risks of corrupt power grabbing (Béné *et al.*, 2009).

Mainstreaming of the different values attributed to fisheries may also support the FAO goals of an ecosystem-based approach to management (FAO, 2009). Some even now posit that a balanced exploitation of species and life history stages relative to productivity in an effort to maintain ecosystem structure could favour small-scale mixed fisheries and sustainably redress some of the global inequities. Although at this point empirical support is limited (Burgess *et al.*, 2015; Kolding *et al.*, 2016) with a problem as systemic as that described here, a dramatic change, if well informed, may not constitute an overreaction. The remaining inequity in fisheries is an urgent matter of global sustainability and human rights (Charles, 2011). There is a pressing need to normalize current policy, supported by institutional research and address undermining flaws. Managers need to continue to innovate according to local contexts and social and environmental change.

Such action requires a global management commitment and a consequential adjustment to the nature of the science conducted. Managers and scientists need to take a pre-emptive view as new technologies become integrated more widely and similarly, as the recent conversations over high-seas governance continues. We recommend that, in the near future, stakeholders, managers and scientists ensure the developmental gap is bridged at this scale, consideration is given to direct and indirect access to the fisheries and establish equity as a key goal in the largest, open access resource in the world.

QUESTION 6: WHAT ARE THE GAPS IN INVOLVEMENT AND REPRESENTATION OF WOMEN IN VALUING AND MANAGING FISH AND FISHERIES?

There are significant gaps in the involvement and representation of women when valuing fish and fisheries around the world and it is important to recognize women's role in food security (Williams *et al.*, 2002; FAO, 2012b). In 2016, the world was 49.6% female (WB, 2017) and yet this significant proportion is not evident in nearly all aspects of fisheries management in both developed and developing communities (Leisher *et al.*, 2016). At the most basic level, women's catch data are often ignored,

whilst men's offshore, commercial catch is noted. This is crucial to valuing a fishery as exploitation levels are not properly realized (Teitze *et al.*, 2000). There are 56 million women world-wide that are directly involved in small-scale fisheries (WB, 2012) and yet women are often not present or welcome at fisheries management meetings, which are often considered to be a man's business (Koralagama *et al.*, 2017). This has a large economic consequence as knowledge is missed from conversations concerning fisheries management (Novaczek & Tarisesei, 2005). Another issue concerning inequality in valuing and managing fisheries is a shortage of female fisheries scientists. One in four fisheries scientists in the U.S.A. is a woman (Arismendi & Penaluna, 2016). Diverse workforces improve scientific productivity (Horta, 2013) and have better problem-solving capacities (Østergaard *et al.*, 2011). Therefore, allowing under-representation to continue may hinder the progression of fisheries science and the development of management practices.

How can this significant issue be rectified? Williams *et al.* (2002) argue that the emphasis on community support and involvement is more important, thus promoting equal opportunities for men and women, rather than adding women-only components to fisheries projects. Therefore, fisheries agencies and institutions need to be encouraged to support the introduction, development and retention of women and men. It is also important to inspire women to enrol in marine biology and fisheries courses so that more of them can be employed in fisheries agencies and institutions. Women can be powerful advocates of fisheries management, regardless of background or education. Ultimately, this is a global issue and it is up to managers and institutions to create a local climate that is welcoming and offers mentors, as well as opportunities for leadership and clear guidelines. Promotion is important for the retention of a diverse workforce.

We recommend that further research is conducted to highlight the continuing disparities in equality regarding valuing and managing fish populations and that all future research surrounding fisheries ensures outreach to and inclusion of women in all capacities.

QUESTION 7: WHY IS IT IMPORTANT TO RECOGNIZE AND SAFEGUARD GENETIC DIVERSITY OF WILD FISHES (AND HOW CAN GENOMICS HELP)?

Genetic diversity is a prerequisite for species resilience and adaptability to environmental changes of stochastic nature, as well as anthropogenic pressures. Consequently, maintenance of genetic variation has long been recognized as indispensable for sustainable management of fish populations (Ryman, 1981).

As of late, rapid technological advances have rendered large-scale sequencing projects amenable even to non-model species (Ekblom & Galindo, 2010). Consequently, modern molecular methods offer a cornucopia of approaches to appreciate the value of fish populations (Kelley *et al.*, 2016). Yet, the lack of implementation of existing policies using genetic knowledge and 'harnessing the power of genomics' remains an issue to date (Laikre *et al.*, 2010a; Shafer *et al.*, 2015; Bernatchez *et al.*, 2017). We therefore highlight a few of the benefits of integrative genetic studies and call for further research, communication and implementation, but also see Ovenden *et al.* (2015).

Genetically sustainable management requires a detailed understanding of how fish diversity is distributed in space and time (Ryman *et al.*, 1995; Volckaert, 2015).

Metabarcoding studies for example assist in defining food webs (Pompanon *et al.*, 2012) and uncovering fish–microbiome associations (Tarnecki *et al.*, 2017). Modern integrative taxonomy is needed to delimit species boundaries (Díaz-Arce *et al.*, 2016; Beheregaray *et al.*, 2017) and population genomics is imperative to assess intraspecific heterogeneity of fish populations (Hemmer-Hansen *et al.*, 2014). Such knowledge is a prerequisite to define biologically meaningful management units (Waples *et al.*, 2008). Reduced representation sequencing methods (Andrews *et al.*, 2016) and shallow whole genome resequencing (Fuentes-Pardo & Ruzzante, 2017) also allow screening of adaptive diversity if designed accordingly (Hoban *et al.*, 2016). As a result, many cases of locally adapted or otherwise cryptic population differentiation patterns have been uncovered (Lamichhaney *et al.*, 2012; Milano *et al.*, 2014; Vandamme *et al.*, 2014; Berg *et al.*, 2015). Such studies are key to avoid loss of unrecognized diversity. In fact, they suggest it would be valuable to routinely monitor genetic diversity, at least in highly commercial species. Genomic monitoring can shed light on the often subtle molecular processes underlying adaptation to environmental changes (Bernatchez, 2016). In addition, these data are needed to disentangle signals from fisheries-induced evolution, phenotypic plasticity and response to environmental stochasticity (Allendorf & Hard, 2009; Hansen *et al.*, 2012). Finally, direct interventions, such as genetic rescue, would also benefit from genetic monitoring (Whiteley *et al.*, 2014). Large-scale releases of translocated individuals from wild or captive populations, which have been carried out to meet commercial and recreational fisheries demands, need to consider genetic aspects in order to be beneficial (Laikre *et al.*, 2010b).

We foresee four main focus areas for implementation, research and development to recognize and safeguard genetic diversity of wild fishes: integrative connectivity and population structure assessments to refine existing fisheries management units and define units in newly developing fisheries (*e.g.* deep-sea and polar fisheries; tropical fisheries in developing countries); regular and standardized monitoring of standing genetic variation and adaptive diversity in key species for early detection of depletion, changes in structure and response to environmental change; investigating and monitoring how and to what extent active interference (relocation, stock enhancement, genetic rescue) can help managing wild fish populations without compromising genetic diversity; regular and comprehensible communication efforts between scientists and stakeholders and managers as described further in the following question are particularly important when it comes to molecular approaches (Bernatchez *et al.*, 2017).

QUESTION 8: HOW CAN THE VALUE OF SCIENTIFIC RESEARCH BE INCREASED THROUGH INFORMING FISH POPULATIONS AND FISHERIES MANAGEMENT?

It is vital that scientific research informs conservation and management, not only to ensure effective measures are implemented (Pullin & Knight, 2001; Sutherland *et al.*, 2004), but also to improve understanding amongst key decision makers of the multiple values of fish populations. Decision-makers (*e.g.* government departments, protected area managers, fisheries directors) tend to have limited time to identify and read relevant scientific papers. Instead, it is the role of the scientist to ensure their work is accessible, provided in a timely manner to coincide with management decisions and the science is salient, credible and legitimate (Cash *et al.*, 2003). This information,

wherever possible, should be multidisciplinary in nature to increase awareness amongst decision-makers of the multiple values of fish populations.

With greater experience of using techniques to monitor and evaluate conservation interventions (Stem *et al.*, 2005; Margoluis *et al.*, 2009), there is scope to develop conservation assessment indices for scientific research. This could complement the widely-used journal impact factor, to credit those scientists who ensure their research actively contributes to conservation and management.

There are three key steps to achieve greater conservation benefits. First, evidence to governments must be provided to inform policy. Many countries will have an established mechanism, such as a scientific advisory committee, to allow scientists to provide evidence at the right moment to inform a decision-making process. When providing advice, it is vital for scientists to describe clearly the evidence, express the risk associated with different policy options and avoid showing personal preference for one policy option over another (Boyd, 2013). In addition, scientists can show relevant officers how the outcomes of their research help achieve the biodiversity targets and international conventions to which the country is signed. Second, work alongside boundary organizations. Environmental non-governmental organizations and conservation charities have widespread experience communicating scientific outcomes to a wider audience, bringing stakeholders together in workshops to develop management strategies and being independent bodies to facilitate knowledge exchange (Cook *et al.*, 2013). By linking with an appropriate boundary organization, the outcome of scientific research can be directly used in management decisions. Third, but not necessarily finally, communicate scientific research to non-specialist audiences. The majority of scientific research is published in journals requiring subscriptions (Pullin & Knight, 2005; Matzek *et al.*, 2014). Creation of non-technical summary documents, guidance documents or briefing notes is fundamental to improve accessibility of research to decision makers (Walsh *et al.*, 2015).

CONCLUSION

Fisheries resource management mandates the managing of human behaviour. Hence, it is essential to consider social, cultural and economic factors as well as understanding the biological and ecological factors affecting exploited fish populations (Fulton *et al.*, 2011). From fish population genetics to the inclusion of women in management, further research on the values of fish populations is needed. To do this effectively, an interdisciplinary approach is imperative. Providing more inclusive measures of the value of natural capital such as fish would also reduce the incentive to overexploit fish populations. It is hoped that the questions posed here (Table I) might pave the way towards this goal.

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REFERENCES

- Allendorf, F. W. & Hard, J. J. (2009). Human-induced evolution caused by unnatural selection through harvest of wild animals. *PNAS* **106**, 9987–9994.
- Allison, E. H., Perry, A. L., Badjeck, M.-C., Adjor, W. N., Brown, K., Conway, D., Halls, A. S., Pilling, G. M., Reynolds, J. D., Andrew, N. L. & Dulvy, N. K. (2009). Vulnerability of national economies to the impacts of climate change on fisheries. *Fish and Fisheries* **10**, 173–196.
- Andrews, K. R., Good, J. M., Miller, M. R., Luikart, G. & Hohenlohe, P. A. (2016). Harnessing the power of RADseq for ecological and evolutionary genomics. *Nature Reviews Genetics* **17**, 81–92.
- Arismendi, I. & Penaluna, B. (2016). Examining diversity inequities in fisheries science: a call to action. *Bioscience* **66**, 584–591.
- Arlinghaus, R. & Cooke, S. J. (2009). Recreational fisheries: socioeconomic importance, conservation issues and management challenges. In *Recreational Hunting, Conservation and Rural Livelihoods: Science and Practice* (Dickson, B., Hutton, J. & Adams, W. A., eds), pp. 39–58. Oxford: Wiley-Blackwell.
- Arlinghaus, R., Mehner, T. & Cowx, I. G. (2002). Reconciling traditional inland fisheries management and sustainability in industrialized countries, with emphasis on Europe. *Fish and Fisheries* **3**, 261–316.
- Arlinghaus, R., Tillner, R. & Bork, M. (2015). Explaining participation rates in recreational fishing across industrialised countries. *Fisheries Management and Ecology* **22**, 45–55.
- Barbier, E. B., Hacker, S. D., Kennedy, C., Koch, E. W., Stier, A. C. & Silliman, B. R. (2011). The value of estuarine and coastal ecosystem services. *Ecological Monographs* **8**, 169–193.
- Beard, T. D., Arlinghaus, R., Cooke, S. J., McIntyre, P. B., De Silva, S., Bartley, D. & Cowx, I. G. (2011). Ecosystem approach to inland fisheries: research needs and implementation strategies. *Biology Letters* **7**, 481–483.
- Beheregaray, L. B., Pfeiffer, L. V., Attard, C. R. M., Sandoval-Castillo, J., Domingos, F. M. C. B., Faulks, L. K., Gilligan, D. M. & Unmack, P. (2017). Genome-wide data delimits multiple climate-determined species ranges in a widespread Australian fish, the golden perch (*Macquaria ambigua*). *Molecular Phylogenetics and Evolution* **111**, 65–75.
- Béné, C., Belal, E., Baba, M. O., Ovie, S., Raji, A., Malasha, I., Njaya, F., Na Andi, M., Russell, A. & Neiland, A. (2009). Power struggle, dispute and alliance over local resources: analyzing ‘democratic’ decentralization of natural resources through the lenses of African inland fisheries. *World Development* **37**, 1935–1950.
- Béné, C., Hersoug, B. & Allison, E. H. (2010). Not by rent alone: analysing the pro-poor functions of small-scale fisheries in developing countries. *Development Policy Review* **28**, 325–358.
- van den Berg, A., Koole, S. & Van der Wulp, N. (2003). Environmental preference and restoration: (how) are they related? *Journal of Environmental Psychology* **23**, 135–146.
- Berg, P. R., Jentoft, S., Star, B., Ring, K. H., Knutsen, H., Lien, S., Jakobsen, K. S. & André, C. (2015). Adaptation to low salinity promotes genomic divergence in Atlantic cod (*Gadus morhua* L.). *Genome Biology and Evolution* **7**, 1644–1663.
- Bernatchez, L. (2016). On the maintenance of genetic variation and adaptation to environmental change: considerations from population genomics in fishes. *Journal of Fish Biology* **89**, 2519–2556. <https://doi.org/10.1111/jfb.13145>
- Bernatchez, L., Wellenreuther, M., Aráneda, C., Ashton, D. T., Barth, J. M. I., Beacham, T. D., Maes, G. E., Martinsohn, J. T., Miller, K. M., Naish, K. A., Ovenden, J. R., Primmer, C. R., Young Suk, H., Therkildsen, N. O. & Withler, R. E. (2017). Harnessing the power of genomics to secure the future of seafood. *Trends in Ecology & Evolution* **32**, 1–16.
- Bowler, D., Buyung-Ali, L., Knight, T. & Pullin, A. (2010). A systematic review of evidence for the added benefits to health of exposure to natural environments. *BMC Public Health* **10**, 456. <https://doi.org/10.1186/1471-2458-10-456>
- Boyd, I. (2013). Point of view: making science count in government. *eLife* **2**, e01061.
- Burgess, M. G., Diekert, F. K., Jacobsen, N. S., Andersen, K. H. & Gaine, S. D. (2015). Remaining questions in the case for balanced harvesting. *Fish and Fisheries* **17**, 1216–1226.

- Callicott, J. B. (1989). *In Defense of the Land Ethic: Essays in Environmental Philosophy*. Albany, NY: Suny Press.
- Cash, D. W., Clark, W. C., Alcock, F., Dickson, N. M., Eckley, N., Guston, D. H., Jager, J. & Mitchell, R. B. (2003). Knowledge systems for sustainable development. *Proceedings of the National Academy of Sciences of the United States of America* **100**, 8086–8091.
- Cawthorn, D. M. & Mariani, S. (2017). Global trade statistics lack granularity to inform traceability and management of diverse and high-value fishes. *Scientific Reports* **7**, 12852.
- Chan, K. M. A., Satterfield, T. & Goldstein, J. (2012). Rethinking ecosystem services to better address and navigate cultural values. *Ecological Economics* **74**, 8–18.
- Charles, A. T. (2011). Human rights and fishery rights in small-scale fisheries management. In *Managing Small-Scale Fisheries: Frameworks and Approaches* (Pomeroy, R. S. & Andrew, N. L., eds), pp. 59–74. Wallingford: CABI Publishing.
- Cisneros-Montemayor, A. M. & Sumaila, U. R. (2010). A global estimate of benefits from ecosystem-based marine recreation: potential impacts and implications for management. *Journal of Bioeconomics* **12**, 245–268.
- Close, D. A., Fitzpatrick, M. S. & Hiram, W. L. (2002). The ecological and cultural importance of a species at risk of extinction, Pacific lamprey. *Fisheries Management Feature* **27**, 19–25.
- Cochrane, K. L. (2000). Reconciling sustainability, economic efficiency and equity in fisheries: the one that got away? *Fish and Fisheries* **1**, 2–21.
- Coleman, F. C., Figueira, W. F., Ueland, J. S. & Crowder, L. B. (2004). The impact of United States recreational fisheries on marine fish populations. *Science* **305**, 1958–1960.
- Cook, C. N., Mascia, M. B., Schwartz, M. W., Possingham, H. P. & Fuller, R. A. (2013). Achieving conservation science that bridges the knowledge–action boundary. *Conservation Biology* **27**, 669–678.
- Cooke, S. J. & Cowx, I. G. (2004). The role of recreational fishing in global fish crises. *BioScience* **54**, 857–859.
- Cooke, S. J. & Cowx, I. G. (2006). Contrasting recreational and commercial fishing: searching for common issues to promote unified conservation of fisheries resources and aquatic environments. *Biological Conservation* **128**, 93–108.
- Cooke, S. J., Schreer, J. F., Dunmall, K. M. & Philipp, D. P. (2002). Strategies for quantifying sub-lethal effects of marine catch-and-release angling: insights from novel freshwater applications. In *Catch and Release in Marine Recreational Fisheries* (Lucy, J. A. & Studholme, A. L., eds), pp. 121–134. *American Fisheries Society Symposium* 30. Bethesda, MD: American Fisheries Society.
- Costanza, R., D'Arge, R., de Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R. V., Paruelo, J., Raskin, R. G., Sutton, P. & van den Belt, M. (1997). The value of the world's ecosystem services and natural capital. *Nature* **387**, 253–260.
- Coulthard, S., Johnson, D. & McGregor, J. A. (2011). Poverty, sustainability and human well-being: a social well-being approach to the global fisheries crisis. *Global Environmental Change* **21**, 453–463.
- Cowx, I. G. (2002). Recreational fishing. In *Handbook of Fish Biology and Fisheries* (Hart, P. J. B. & Reynolds, J. D., eds), pp. 367–390. Oxford: Blackwell Science Ltd.
- Cracknell, D., White, M., Pahl, S., Nichols, W. & Depledge, M. (2016). Marine biota and psychological well-being: a preliminary examination of dose-response effects in an aquarium setting. *Environment and Behaviour* **48**, 1242–1269.
- Dallimer, M., Irving, K., Skinne, A., Davies, Z., Rouquette, J., Maltby, L. & Gaston, K. J. (2012). Biodiversity and the feel-good factor: understanding associations between self-reported human well-being and species richness. *Bioscience* **62**, 47–55.
- Díaz-Arce, N., Arrizabalaga, H., Murua, H., Irigoien, X. & Rodríguez-Ezpeleta, N. (2016). RAD-Seq derived genome-wide nuclear markers resolve the phylogeny of tunas. *Molecular Phylogenetics and Evolution* **102**, 202–207.
- Dyck, A. J. & Sumaila, U. R. (2010). Economic impact of ocean fish populations in the global fishery. *Journal of Bioeconomics* **12**, 227–243.
- Eklom, R. & Galindo, J. (2010). Applications of next generation sequencing in molecular ecology of non-model organisms. *Heredity* **107**, 1–15.
- FAO (2008). *The State of World Fisheries and Aquaculture 2008*. Rome: UN Food & Agriculture Organization.

- FAO (2009). *The Ecosystem Approach to Fisheries. FAO Technical Guidelines for Responsible Fisheries 4*. Rome: UN Food & Agriculture Organization.
- FAO (2012a). *Recreational Fisheries. FAO Technical Guidelines for Responsible Fisheries 13*. Rome: UN Food & Agriculture Organization.
- FAO (2012b). *The State of World Fisheries and Aquaculture 2012*. Rome: UN Food & Agriculture Organization.
- FAO (2015). *Voluntary Guidelines for Securing Sustainable Small-Scale Fisheries in the Context of Food Security and Poverty Eradication*. Rome: UN Food & Agriculture Organization.
- FAO (2016). *The State of World Fisheries and Aquaculture 2016*. Rome: UN Food & Agriculture Organization.
- Ficke, A. D., Myrick, C. A. & Hansen, L. J. (2007). Potential impacts of global climate change on freshwater fisheries. *Reviews in Fish Biology and Fisheries* **17**, 581–613.
- Fuentes-Pardo, A. P. & Ruzzante, D. E. (2017). Whole-genome sequencing approaches for conservation biology: advantages, limitations and practical recommendations. *Molecular Ecology* **20**, 5369–5406.
- Fuller, R., Irvine, K., Devine-Wright, P., Warren, P. & Gaston, K. (2007). Psychological benefits of green space increase with biodiversity. *Biology Letters* **3**, 390–394.
- Fulton, E. A., Smith, A. D. M., Smith, D. C. & van Putten, I. E. (2011). Human behaviour: the key source of uncertainty in fisheries management. *Fish and Fisheries* **12**, 2–17.
- Genner, M. J., Sims, D. W., Wearmouth, V. J., Southall, E. J., Southward, A. J., Henderson, P. A. & Hawkins, S. J. (2004). Regional climatic warming drives long-term community changes of British marine fish. *Proceeding of the Royal Society of London* **271**, 655–661.
- Ghermandi, A. & Nunes, P. A. (2013). A global map of coastal recreation values: results from a spatially explicit meta-analysis. *Ecological Economics* **86**, 1–15.
- Hansen, M. M., Olivieri, I., Waller, D. M. & Nielsen, E. E. (2012). Monitoring adaptive genetic responses to environmental change. *Molecular Ecology* **21**, 1311–1329.
- Hargrove, E. C. (1992). Weak anthropocentric intrinsic value. *The Monist* **75**, 183–207.
- Hemmer-Hansen, J., Therkildsen, N. O. & Pujolar, J. M. (2014). Population genomics of marine fishes: next-generation prospects and challenges. *Biological Bulletin* **227**, 117–132.
- Hoban, S., Kelley, J. L., Lotterhos, K. E., Antolin, M. F., Bradburd, G., Lowry, D. B., Poss, M. L., Reed, L. K., Storfer, A. & Whitlock, M. C. (2016). Finding the genomic basis of local adaptation: pitfalls, practical solutions and future directions. *The American Naturalist* **188**, 379–397.
- Holmlund, C. M. & Hammer, M. (1999). Ecosystem services generated by fish populations. *Ecological Economics* **29**, 253–268.
- Horta, H. (2013). Deepening our understanding of academic inbreeding effects on research information exchange and scientific output: new insights for academic based research. *Higher Education* **65**, 487–510.
- Kawall, J. A. (2017). History of environmental ethics. In *The Oxford Handbook of Environmental Ethics* (Gardiner, S. M. & Thompson, M., eds), pp. 13–26. Oxford: Oxford University Press. <https://doi.org/10.1093/oxfordhb/9780199941339.013.6>
- Kelley, J. L., Brown, A. P., Therkildsen, N. O. & Foote, A. D. (2016). The life aquatic: advances in marine vertebrate genomics. *Nature Reviews Genetics* **17**, 523–534.
- King, T., Kilpatrick, S., Willis, K. & Speldewinde, C. (2015). “A different kettle of fish”: mental health strategies for Australian fishers and farmers. *Marine Policy* **60**, 134–140.
- Kolding, J., Garcia, S. M., Zhou, S. & Heino, M. (2016). Balanced harvest: utopia, failure, or a functional strategy? *ICES Journal of Marine Science* **73**, 1616–1622.
- Koralagama, D., Gupta, J. & Pouw, N. (2017). Inclusive development from a gender perspective in small scale fisheries. *Current Opinion in Environmental Sustainability* **16**, 1–6.
- Laikre, L., Allendorf, F. W., Aroner, L. C., Baker, C. S., Gregovich, D. P., Hansen, M. M., Jackson, J. A., Kendall, K. C., McKelvey, K., Neel, M. C., Neel, M. C., Olivieri, I., Ryman, N., Schwartz, M. K., Bull, R. S., Stetz, J. B., Tallmon, D. A., Taylor, B. L., Vojta, C. D., Waller, D. S. & Waples, R. S. (2010a). Neglect of genetic diversity in implementation of the convention on biological diversity. *Conservation Biology* **24**, 86–88.
- Laikre, L., Schwartz, M. K., Waples, R. S. & Ryman, N. (2010b). Compromising genetic diversity in the wild: unmonitored large-scale release of plants and animals. *Trends in Ecology and Evolution* **25**, 520–529.

- Lamichhaney, S., Barrio, A. M., Rafati, N., Sundstrom, G., Rubin, C. J., Gilbert, E. R., Berglund, J., Wetterbom, A., Laikre, L. & Webster, M. T. (2012). Population-scale sequencing reveals genetic differentiation due to local adaptation in Atlantic herring. *Proceedings of the National Academy of Sciences of the United States of America* **109**, 19345–19350.
- Last, P. R., White, W. T., Gledhill, D. C., Hobday, A. J., Brown, R., Edgar, G. J. & Pecl, G. (2011). Long-term shifts in abundance and distribution of a temperate fish fauna: a response to climate change and fishing practices: long-term shifts in a temperate fish fauna. *Global Ecology and Biogeography* **20**, 58–72.
- Leisher, C., Temsah, G., Booker, F., Day, M., Samberg, L., Prosnitz, D., Agarwal, B., Matthews, E., Roe, D., Russell, D., Sunderland, T. & Wilkie, D. (2016). Does gender composition of forest and fishery management groups affect resource governance and conservation outcomes? A systematic map. *Environmental Evidence* **5**, 6. <https://doi.org/10.1186/s13750-016-0057-8>
- Lewin, W. C., Arlinghaus, R. & Mehner, T. (2006). Documented and potential biological impacts of recreational fishing: insights for management and conservation. *Reviews in Fisheries Science* **14**, 305–367.
- Lewis, S. L. & Maslin, M. A. (2015). Defining the Anthropocene. *Nature* **519**, 171–180.
- Luck, G. W., Davidson, P., Boxall, D. & Smallbone, L. (2011). Relations between urban bird and plant communities and human well-being and connection to nature. *Conservation Biology* **25**, 816–826.
- Magurran, A. E., Dornelas, M., Moyes, F., Gotelli, N. J. & McGill, B. (2015). Rapid biotic homogenization of marine fish assemblages. *Nature Communications* **6**, 8405.
- Margoluis, R., Stem, C., Salafsky, N. & Brown, M. (2009). Design alternatives for evaluating the impact of conservation projects. *New Directions for Evaluation* **2009**, 85–96.
- Maslin, M. A. & Lewis, S. L. (2015). Anthropocene: earth system, geological, philosophical and political paradigm shifts. *The Anthropocene Review* **2**, 108–116.
- Matzek, V., Covino, J., Funk, J. L. & Saunders, M. (2014). Closing the knowing–doing gap in invasive plant management: accessibility and interdisciplinarity of scientific research. *Conservation Letters* **7**, 208–215.
- Milano, I., Babbucci, M., Cariani, A., Atanassova, M., Bekkevold, D., Carvalho, G. R., Espiñeira, M., Fiorentino, F., Garofalo, G., Geffen, A. J., Hansen, H., Helyar, S. J., Nielsen, E. E., Ogden, R., Patarnello, T., Stagioni, M., FishPopTrace Consortium, Tinti, F. & Bargelloni, L. (2014). Outlier SNP markers reveal fine-scale genetic structuring across European hake populations (*Merluccius merluccius*). *Molecular Ecology* **23**, 118–135.
- Novaczek, I. & Tarisesei, J. (2005). Gender, generational perceptions and community fisheries management in Lelepa, North Efate, Vanuatu. In *Pacific Voices: Equity and Sustainability in Pacific Islands Fisheries* (Novaczek, I., Mitchell, J. & Veitayaki, J., eds). Suva: Institute of Pacific Studies, University of the South Pacific.
- OCED (1996). *Oxford Compact English Dictionary*. Oxford: Oxford University Press.
- Østergaard, C., Timmermans, B. & Kristinsson, K. (2011). Does a different view create something new? The effect of employee diversity on innovation. *Research Policy* **40**, 500–509.
- Ovenden, J. R., Berry, O., Welch, D. J., Buckworth, R. C. & Dichmont, C. M. (2015). Ocean's eleven: a critical evaluation of the role of population, evolutionary and molecular genetics in the management of wild fisheries. *Fish and Fisheries* **16**, 125–159.
- Pauly, D. & Zeller, D. (2016). Catch reconstructions reveal that global marine fisheries catches are higher than reported and declining. *Nature Communications* **7**, 10244. <https://doi.org/10.1038/ncomms10244>
- Piccolo, J. J. (2017). Intrinsic values in nature: objective good or simply half of an unhelpful dichotomy? *Journal for Nature Conservation* **37**, 8–11.
- Pikitch, E. K., Snator, C., Babcock, E. A., Bakun, A., Bonfil, R., Conover, D. O., Dayton, P., Doukakis, P., Fluharty, D., Heneman, B., Houde, E. D., Link, J., Livingston, P. A., Mangel, M., McAllister, M. K., Pope, J. & Sainsbury, M. J. (2004). Ecosystem-based fishery management. *Science* **305**, 346–347.
- Pitcher, T. J. & Hollingworth, C. (2008). *Recreational Fisheries: Ecological, Economic and Social Evaluation*. Hoboken, NJ: John Wiley & Sons.

- Pompanon, F., Deagle, B. E., Symondson, W. O. C., Brown, D. S., Jarman, S. N. & Taberlet, P. (2012). Who is eating what: diet assessment using next generation sequencing. *Molecular Ecology* **21**, 1931–1950.
- Post, J. R., Sullivan, M., Cox, S., Lester, N. P., Walters, C. J., Parkinson, E. A., Paul, A. J., Jackson, L. & Shuter, B. J. (2002). Canada's recreational fisheries: the invisible collapse? *Fisheries* **27**, 6–17.
- Pramod, G., Nakamura, K., Pitcher, T. J. & Delagran, L. (2014). Estimates of illegal and unreported fish in seafood imports to the USA. *Marine Policy* **48**, 102–113.
- Pullin, A. S. & Knight, T. M. (2001). Effectiveness in conservation practice: pointers from medicine and public health. *Conservation Biology* **15**, 50–54.
- Pullin, A. S. & Knight, T. M. (2005). Assessing conservation management's evidence base: a survey of management-plan compilers in the United Kingdom and Australia. *Conservation Biology* **19**, 1989–1996.
- Rolston, H. I. I. (2012). *A New Environmental Ethics: The Next Millennium for Life on Earth*. New York, NY: Routledge.
- Rolston, H. III (1975). Is there an ecological ethic? *Ethics* **85**, 93–109.
- Ryman, N. (1981). Conservation of genetic resources: experiences from the brown trout (*Salmo trutta*). In *Fish Gene Pools* (Ryman, N., ed), pp. 61–74. *Ecological Bulletin* **34**. Stockholm: Oikos Editorial Office.
- Ryman, N., Utter, F. & Laikre, L. (1995). Protection of intraspecific biodiversity of exploited fishes. *Reviews in Fish Biology and Fisheries* **5**, 417–446.
- Sandifer, P., Sutton-Grier, A. & Ward, B. (2015). Exploring connections among nature, biodiversity, ecosystem services and human health and well-being: opportunities to enhance health and biodiversity conservation. *Ecosystem Services* **12**, 1–15.
- Sarukhán, J. & Whyte, A. (Eds) (2005). *Millennium Ecosystem Assessment. Synthesis: Ecosystems and Human Well-Being: Wetlands and Water*. Washington, D.C.: Island Press.
- Shafer, A. B. A., Wolf, J. B. W., Alves, P. C., Bergström, L., Bruford, M. W., Brännström, I., Colling, G., Dalén, L., De Meester, L., Ekblom, R., Fawcett, K. D., Fior, S., Hajibabaei, M., Hill, J. A., RusHoezel, A., Höglund, J., Jensen, E. L., Krause, J. & Zieliński, P. (2015). Genomics and the challenging translation into conservation practice. *Trends in Ecology and Evolution* **30**, 78–87.
- Soulé, M. (1985). What is conservation biology? A new synthetic discipline addresses the dynamics and problems of perturbed species, communities and ecosystems. *Bioscience* **35**, 727–734.
- Stem, C., Margoluis, R., Salafsky, N. & Brown, M. (2005). Monitoring and evaluation in conservation: a review of trends and approaches. *Conservation Biology* **19**, 295–309.
- Sutherland, W. J., Pullin, A. S., Dolman, P. M. & Knight, T. M. (2004). The need for evidence-based conservation. *Trends in Ecology and Evolution* **19**, 305–308.
- Tarnecki, A. M., Burgos, F. A., Ray, C. L. & Arias, C. R. (2017). Fish intestinal microbiome: diversity and symbiosis unraveled by metagenomics. *Journal of Applied Microbiology* **123**, 2–17.
- Teitze, U., Groenewold, G. & Marcoux, A. (2000). *Demographic Change in Coastal Fishing Communities and its Implications for the Coastal Environment*. Fisheries Technical Paper **403**. Rome: FAO.
- Ulrich, R. S. (1984). View through a window may influence recovery from surgery. *Science* **224**, 420–421.
- Vandamme, S. G., Maes, G. E., Raeymaekers, J. A. M., Cottenie, K., Imsland, A. K., Hellemans, B., Lacroix, G., Mac Aoidh, E., Martinsohn, J. T., Martínez, P., Robbens, J., Vilas, R. & Volckaert, F. A. (2014). Regional environmental pressure influences population differentiation in turbot (*Scophthalmus maximus*). *Molecular Ecology* **23**, 618–636.
- Velarde, M., Fry, G. & Tveit, M. (2007). Health effects of viewing landscapes – landscape types in environmental psychology. *Urban Forestry and Urban Greening* **6**, 199–212.
- Volckaert, F. A. M. (2015). Applying the hidden treasures of population biodiversity to decision making and management. *Ocean and Coastal Management* **118**, 47–50.
- Vucetich, J. A., Bruskotter, J. T. & Nelson, M. P. (2015). Evaluating whether nature's intrinsic value is an axiom of or anathema to conservation. *Conservation Biology* **29**, 321–332.
- Walsh, J. C., Dicks, L. V. & Sutherland, W. J. (2015). The effect of scientific evidence on conservation practitioners' management decisions. *Conservation Biology* **29**, 88–98.

- Waples, R. S., Punt, A. E. & Cope, J. M. (2008). Integrating genetic data into management of marine resources: how can we do it better? *Fish and Fisheries* **9**, 423–449.
- Washington, H., Taylor, B., Kopnina, H., Cryer, P. & Piccolo, J. J. (2017). Why ecocentrism is the key pathway to sustainability. *The Ecological Citizen* **1**, 35–41.
- Watson, R. A., Green, B. S., Tracey, R. S., Farmery, A. & Pitcher, T. J. (2016). Provenance of global seafood. *Fish and Fisheries* **17**, 585–595.
- Whiteley, A. R., Fitzpatrick, S. W., Funk, W. C. & Tallmon, D. A. (2014). Genetic rescue to the rescue. *Trends in Ecology and Evolution* **30**, 42–49.
- Winfield, I. J. (2016). Recreational fisheries in the UK: natural capital, ecosystem services, threats and management. *Fisheries Science* **82**, 203–212.

Electronic References

- Binet, T. & Failler, P. (2011). *A Critical Review of the European Union-West African Fisheries Agreements*. Paris: A Planet for Life. Available at www.regardssurlaterre.com/en/critical-review-european-union-west-african-fisheries-agreements
- Callicott, J. B. (2006). Conservation values and ethics. In *Principles of Conservation Biology* (Groom, M. J., Meffe, G. K. & Carroll, C. R., eds). Sunderland, MA: Sinauer. Available at www.sites.sinauer.com/groom/chapter4.html
- CIESIN (2012). *Percentage of Total Population Living on Coastal Areas*. New York, NY: Columbia University, Center for International Earth Science Information Network. Available at www.un.org/esa/sustdev/natlinfo/indicators/methodology_sheets/oceans_seas_coasts/pop_coastal_areas.pdf and http://sedac.ciesin.columbia.edu/es/papers/Coastal_Zone_Pop_Method.pdf
- Convention on Biological Diversity (2001). Global implementation of the convention and cooperation with other conventions and processes. In *Convention on Biological Diversity (2001) Global Biodiversity Outlook* (Secretariat of the Convention on Biological Diversity, ed.), pp. 191–236. Montréal, Canada: Secretariat of the Convention on Biological Diversity Available at www.cbd.int/doc/publications/gbo/gbo-acknow-en.pdf
- FoF (2017). *Fish and the Value of Story*. Seattle, WA: Future of Fish. Available at www.futureoffish.org/blog/fish-and-value-story
- MSC (2017). *Global Impacts Report 2017*. 1997–2017: a 20th Anniversary Review of the Marine Stewardship Council Program and the Progress and Improvements Made by Msc Certified Fisheries Around the World. London: Marine Stewardship Council. Available at <https://www.msc.org/documents/environmental-benefits/global-impacts/msc-global-impacts-report-2017>
- PADI (2015). PADI Statistics. Available at www.padi.com/scuba-diving/about-padi/statistics/
- SCB (2017). Enhancing the Impact of Conservation Science: Strategic Plan 2016–2020. Washington, D.C.: Society for Conservation Biology. Available at <https://conbio.org/about-scb/strategic-plan/>
- WB (2012). *Hidden harvest: The Global Contribution of Capture Fisheries*. Economic and Sector Work Report Number 66469-GL. Washington, D.C.: The World Bank. Available at <http://documents.worldbank.org/curated/en/515701468152718292/pdf/664690ESW0P1210120HiddenHarvest0web>
- WB (2017). *Population, Female (% Of Total)*. Washington, D.C.: The World Bank. Available at www.data.worldbank.org/indicator/SP.POP.TOTL.FE.ZS.pdf
- Williams, M., Chao, N., Choo, P., Matics, K., Nandeesh, M., Shariff, M., Siason, I., Tech, E. & Wong, J. (Eds) (2002). *Global Symposium on Women in Fisheries*. Penang: ICLARM, The World Fish Centre. Available at http://pubs.iclarm.net/resource_centre/WF_328.pdf