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**COMMENTARY**

# Sustainability: A flawed concept for fisheries management?

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The concept of sustainable fishing is well ingrained in marine conservation and marine governance. However, I argue that the concept is deeply flawed; ecologically, socially and economically. Sustainability is strongly related, both historically and currently, to maximum long-term economic exploitation of a system. Counter-intuitively, in fisheries, achieving this economic exploitation often relies on government subsidies. While many fish populations are not sustainably fished biologically, even 'sustainably harvesting' fish results in major ecological changes to marine systems. These changes create unknown damage to ecosystem processes, including carbon capture potential of the ocean. The spatial scale of commercial fishing processes can also lead to social and food security issues in local, coastal communities that rely on fish for dietary needs. A radical alternative proposal is provided to the current situation. Ultimately, offshore fishing should be stopped completely and fish catches should rely instead on inshore fisheries. While such an approach may require a change in thinking and human behaviour regarding fish, I demonstrate that there are many benefits of this approach, including ecological, social and to local coastal economies, and few negatives, although management measures and coastal marine protected areas to protect vulnerable species and habitats would still be required. As such, the approach suggested is much more akin to a holistic definition of sustainability or 'prevention of ecological harm', rather than the maximum long-term exploitation of an ecosystem which is an underlying assumption of much fisheries and conservation research. While the suggestions in the study would benefit from further ecological, social and economic modelling, any movement towards restricting offshore catches should provide some degree of the benefits detailed.

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## Sustainable fisheries

In 2018, the UK Department for Environment, Fisheries and Rural Affairs (DEFRA) produced a 25-year environmental plan for the country. Central to the marine section of this plan was a commitment to continue to manage fisheries at maximum sustainable yield (MSY), which the plan highlighted as a recent change to policy from a previous total allowable catch scheme (DEFRA, 2018).

MSY, however, has been a mainstay of fisheries policy since the term was introduced in 1954 (Schaefer, 1954), and is covered in many basic ecological textbooks (e.g., Begon et al., 2006). The concept is simple: populations grow fastest well before they reach carrying capacity. Maintaining a population at its maximum growth level means it will produce the maximum increase in biomass in any given year. Removing only the increase in biomass results in the biomass of the population remaining stable – hence sustainable harvesting is occurring.

While most basic ecological textbooks suggest that MSY occurs at 50% of the carrying capacity, the population dynamics in the marine environment – with 'r' strategists producing many offspring with little parental care in the

plankton – means that MSY can be as low as 20% of the population, with most commercially targeted fish having a population size suitable to harvest at MSY between 20 and 50% of the carrying capacity of their population (Hilborn and Hilborn, 2012). However, despite the popularity of MSY in ecology and fisheries management, it is not the only factor used to manage fisheries, with socio-economic and political concerns also featuring heavily (Botsford et al., 1997; see below). These conflicts of management have led to many fish stocks being classed as overfished, especially high-trophic level species (FAO, 2018). Long-term stability of stocks, and long-term economic benefits, are forfeited for short-term gain – the classic 'tragedy of the commons' response to a common resource (Berkes, 1985).

With important exceptions, some of which are considered later, many fisheries are heavily regulated in a top-down, government-controlled manner (Berkes, 1985). The quotas set and policies developed are often deeply unpopular with fishers. Many of these heavily regulated fisheries are also unsustainable, leading to the question of whether fishing to quotas such as MSY are the best policies for marine conservation and coastal economies. Even certification schemes for sustainable fishing, such as the Marine Stewardship Council scheme, have come under fire for failing to guarantee overfishing (Gulbrandsen, 2005; Christian et al., 2013). In this paper, I examine many

issues with the concept of sustainable fishing from ecological and social perspectives, exploring the concept in both developed and developing nations, and propose a solution to create sustainable fisheries and sustainable fishing communities.

### **An historical context of the concept of sustainability**

The term 'sustainability' appeared relatively recently, appearing in the Oxford English Dictionary less than 70 years ago (Du Pisani, 2006). However, terms with similar meanings have existed in many other languages prior to this time, and discussions of the concept in the scientific literature began earlier, during the early 20<sup>th</sup> century (Hotelling, 1931). The concept of biological sustainability is even older, and generally thought to relate to Malthus' ideas on population growth and, to some extent, some of Darwin's work on evolution in terms of intraspecific competition (Du Pisani, 2006). Some authors also argue that much of the thinking around sustainability by ecological and evolutionary thinkers was guided by fundamental ideas in economics, such as Adam Smith's understanding of efficiency and competition from market forces, as well as Smith's frequently overlooked understanding of limits to economic progress based on the natural environment (Lumley and Armstrong, 2003).

The role of economics in the shaping of the concept of sustainability is interesting, especially given the more recent concept of sustainable development, which seeks to further link the concept of environmental sustainability with economic development, especially in developing nations (Du Pisani, 2006). Many studies have questioned the ability to achieve sustainable development, or posulated that there is a stronger emphasis on economic development than sustainable use of resources (Lélé, 1991; Beckerman, 1994); yet, as discussed below, the concept of biological sustainability itself may, in cases, be ecologically flawed.

There are also many other interpretations of the verb 'to sustain' which do not stem from biological resource use (see discussion in McCormack, 2016). Perhaps because of these other interpretations, recent use of the term 'sustainability' or its grammatical deviations has been hijacked for multiple causes that bear little resemblance to its biological meaning (Hosey, 2017). For example, sustainability reviews have been used solely to indicate financial solvency of organisations such as hospitals (NHS, 2015). The positive environmental and scientific credentials of the term may be providing positive spin on what are largely negative messages (e.g., hospital closure). However, the misuse, or alternative use, of the term has also led to public apathy over the term, and potentially the fundamental concept of sustainable use of resources (Hosey, 2017).

### **Sustainability – an economic and ecological concept, but not a good marine conservation term**

The context for sustainability as applied to fisheries is provided above, but there are many constraints on applying this concept effectively to fisheries management, and

far more when considering how to apply sustainability to marine conservation or indeed to fishing communities. Firstly, estimating the population size of fish stocks is extremely challenging. Typically, a technique called virtual population analysis (VPA) is used to obtain estimates for most commercially fished stocks (Hilborn and Walters, 1992). VPA is an accounting process, which uses caught fish alongside an estimate of natural mortality to hindcast the stock size of fish. Essentially, for a fish such as cod, which is assumed to live to an age of 5 years in many estimates of the International Council for the Exploration of the Sea (ICES) (an age set largely due to fishing pressure, as cod can live 20+ years), VPA can be used to estimate the stock size of cod five years ago. To estimate the current population, we need estimates of recruitment to the population, which are highly variable and, in practice, do not fit well to current models of stock size to recruitment estimates (Brander, 2000).

Secondly, in many countries, especially within the EU, fish stocks have a minimum landing size. Fish below this size are returned to the sea, largely after they have died, in a process called discarding (Arnason, 1994), although in Europe the practice is decreasing due to changes in EU fishing policy (e.g., EU regulation No 1380/2013). As well as being wasteful of fish, discards are not recorded, and the estimation of population size suffers further (e.g., Myers et al., 1997). Multi-species interactions are also an important concern in establishing population size and catch limits. Predators eat prey species, and prey species provide food for predators; as such, fixing a level of mortality for a given fish stock may not be reasonable, as different species will influence each other's population sizes (Pope and Macer, 1996).

Real-time monitoring of catch per unit effort (CPUE) can also be used to identify reductions in population sizes of fish, with a fall in CPUE indicating a declining population (Bordalo-Machado, 2007). However, CPUE can be a source of conflict between fishers and fisheries scientists and managers. CPUE population estimates often assume a spatially homogeneous spread of a stock across the entire area (Bordalo-Machado, 2007). Fishers will naturally fish in areas where catch will be highest, rather than random or regular sampling regimes as conducted by fisheries scientists. Fishing in areas with a high CPUE will therefore artificially inflate stock size figures; hence populations may be considered unsustainable to fisheries managers, yet fishers cannot see any problem or signs of overfishing (see example of industrial sandeel fishery closure in STECF, 2006).

Climate change also has been shown to result in changes in distribution of commercial fish (Perry et al., 2005). Fish stocks in any given geographical location may thus vary beyond what is caused by fishing pressure. This variance is especially problematic if MSY values are calculated using historical hindcasts with techniques such as VPA.

The above examples provide details of the challenge of managing sustainable fisheries. Many of these ideas have been discussed extensively in the literature over the last 50 years (e.g., Larkin, 1977) and, in some cases, have been addressed (reviewed by Smith and Punt, 2001).

There has also been progress in fisheries management. From a technical perspective, estimates of fish stocks are improving, and advances in predictive models and understanding of recruitment continue to address uncertainties (Beaugrand and Kirby, 2010), assess multispecies interactions (Plagányi et al., 2014), and account for discard processes (e.g. Maeda et al., 2017) and climate change (Lynam et al., 2017). Historic declines in some stocks have been reversed, and stocks and ecosystems now show clear trends of recovery (e.g., Worm et al., 2009; ICES, 2017; Lynam et al., 2017). There is also a growing realisation in the industry that sustainability is a valid issue for fish stocks and that fisher representation can create good management policies with greater ecological benefits (Salomon et al., 2011; Di Franco et al., 2016; Stephenson et al., 2016), although where this realisation is absent, there is still a reluctance of fishers to comply with management measures (Boonstra et al., 2017).

However, there is also an issue fundamental to the concept of sustainability in regards to the marine environment that is often overlooked, given the framing of 'sustainability' as a fisheries management goal and the historical economic origins of the term. Fishing to maximum sustainable yield is often seen as one of potentially many goals of successful fisheries management. The latest official figures from the Food and Agriculture Organisation (FAO, 2018) suggest that 33% of global fisheries are 'overfished' (fished beyond MSY), 60% are 'maximum sustainably fished' and 7% are 'underfished' (with underfished a newly defined term for 2018). In terms of food provision, the terms underfished and maximum sustainably fished make sense, indicating well managed or underexploited, respectively. However, in terms of marine conservation, these terms need careful consideration (see discussion in Pauly et al., 2002). Fishing to MSY requires a population at 20 to 50% of the carrying capacity of the population, depending on the species (Hilborn and Hilborn, 2012). This requirement means that somewhere between 50 and 80% of targeted fish populations are removed from the sea, for human consumption, in what is often taken as a well managed fishery, managed to meet sustainable conservation goals. Given that over four times more fisheries are overfished than underfished, the human consumption of fish has likely removed well over 50% of natural fish biomass from the ocean (a precise percentage would be difficult to calculate as data do not exist for all stocks, especially in the high seas, though see estimates in Bar-On et al., 2018).

The term underfished also has clear exploitation connotations, implying linguistically that more should be done to increase the harvest of these stocks, rather than the true meaning that these populations are depleted, but not yet to the extent that their reproductive capacity has been damaged. Note that in management terms, stocks can be purposely underfished (i.e., not fished to levels where MSY would be achieved) for a variety of reasons, including conservation goals.

While the terrestrial environment has certainly been overexploited, with no large-scale harvesting operations for food being viable (although past estimates have

suggested African ungulates may provide some potential; Talbot, 1966), the implications of fish removal for the marine environment are significant. In a recent study, the amount of respiring biomass in the oceans has been estimated at five times that of photosynthetic biomass, with fish making up ~35% of the animal biomass in the ocean (Bar-On et al., 2018). Annelid worms and arthropods (especially in the zooplankton) make up the majority of the remaining animal biomass, but the bulk of biomass (~70%) is comprised of bacteria and protists, most of which are not photosynthetic (Bar-On et al., 2018).

The effects of predatory fish on the structure of marine ecosystems have been well established (Baum and Worm, 2009), and the majority of commercially targeted fish are predatory (Yodzis, 2001). The removal of so many fish, therefore, must have major ecological implications. Changes in the respiring biomass of the ocean have been predicted to result from removal of fish (Spiers et al., 2016), resulting in more CO<sub>2</sub> production and hence less oceanic capacity for absorbing anthropogenic CO<sub>2</sub>, accelerating both climate change and ocean acidification (Spiers et al., 2016). Such changes are also apparent in other studies; for example, Lynam et al. (2017) showed that zooplankton biomass increased as fish stocks decreased across the North Sea, and vice versa as fishing effort changed over time.

Rather than the optimisation of MSY, fisheries management from a conservation perspective needs to consider the ocean more holistically, including damage to the seabed and bycatch issues associated with fishing (Moore and Jennings, 2000). Clearly there is a need for better metrics of environmental health, based on a more holistic understanding of the overall impact of fishing, rather than whether each individual stock could still be able to replenish its population size in the following year.

It has been recommended that conservation works on the precautionary principle (Cooney and Dickson, 2012). To take an analogy from a different discipline, in engineering the strength of a component or structure is calculated through estimation of the forces acting on the component (not unlike the calculations used to estimate population size or MSY). The precautionary principle applied to engineering involves calculating the thickness of the component needed to withstand the forces, then multiplying this thickness by a safety factor. In areas of civil engineering, this factor can be >10 to ensure that no catastrophic failures occur to major structures. In areas where the need for weight reduction is critical and failure might not jeopardise the public, for example, components in a Formula One car engine, the safety factors are much reduced (to as little as 1.15; Iorga et al., 2012).

Given the need for cheap and protein-rich food in many developing countries (Golden et al., 2016), it could be considered fair to argue that MSY is a necessary target, with little room for safety factors (although see discussion below). However, the level of failure of components in Formula One cars is high, largely due to incorrect calculations and low safety factors, despite the work of some of the world's most talented engineers. Following this analogy, managing an uncertain situation in terms of fish

stocks without any safety factors or the use of the precautionary principle could cause inadvertent collapse of these local fisheries (especially in light of climate change and offshore industrial fisheries, considered below) and put many critical food supplies at risk. Again, the lack of applying precaution to the management of fish stocks has been part of an ongoing debate for many years; while not a new argument, it is certainly pertinent to any discussion of sustainable fisheries (for discussions, see Larkin, 1977; Smith and Punt, 2001).

### **Sustainability – not the only goal of fisheries management**

As discussed above, concepts such as MSY and the FAO (2018) definition of an ‘underexploited’ fishery clearly indicate that minimisation of environmental damage is frequently not the goal of fisheries management. Indeed, there is evidence that MSY has been developed as a political tool by the USA to dominate military access to the seas, rather than a conservation method (Finley and Oreskes, 2013). Sustainably harvesting the maximum number of fish is also not the only management goal. While profit drives most commercial fishing, and food provision may play a role in some smaller-scale artisanal sectors, management has the task of balancing conflicting goals of economic and political drivers from the government, socio-economics at the industry level (i.e., ensuring that fishers can make a living and that other aspects of the industry can remain profitable), and fairness of catch allocation, in addition to sustainability and other environmental concerns (Botsford et al., 1997; McCormack, 2016). For example, historically, the total allowable catch for each stock in the EU common fisheries policy was based on scientific advice and then altered (normally upwards, towards increased catches) based on socio-economic factors and stakeholder lobbying (see Daan, 1997, for an overview). Reforms to the Common Fisheries Policy in 2014 placed a greater emphasis on MSY to manage stocks, but placed single stock MSY within an ecosystem-based management context, the precise meaning of which is generally considered unclear (Prellezo and Curtin, 2015). Nevertheless, as emphasised by the 25-year environmental plan of the UK (DEFRA 2018), where it is clear that economic and political concerns are still important, there is a shift to using MSY as a clearer benchmark to allocate quotas within the EU.

Debate also exists over the role of economic factors in management. Theoretically, maximum economic exploitation of a renewable resource can lead to its extinction (Clark, 1973), whereas more detailed examination of harvesting fish stocks to maximum economic yield within likely economic scenarios indicates that the stock biomass at which maximum economic yield occurs is higher than that at which MSY occurs (Grafton et al., 2007). Maximum economic yield can also be calculated in multispecies contexts, where it has shown to provide sustainable harvesting to all of the species, regardless of their economic value (Stafford, 2008). In practice, however, maximum economic gain is long-term and the ‘tragedy of the commons’ rush for short-term gain is still a major driver of overfishing (Berkes, 1985).

The introduction of individual quotas is a mechanism designed to prevent tragedy-of-the-commons scenarios (Grafton, 1996; Degnbol et al., 2006). In these approaches a proportion of the total catch is assigned to different fishers, meaning that they can catch this resource over a longer period of time and not compete with other fishers for the same resource (Grafton, 1996). In practice, such individual quotas are also transferable (or, more accurately, for sale) and individual transferable quotas (ITQs) allow smaller operators to sell quotas to larger operators. There have been successes of ITQs in terms of recovery of fish stocks (Costello et al., 2008); however, they have also been criticised in terms of unfair allocations to some communities, and especially to indigenous groups (McCormack, 2016).

Degnbol et al. (2006) reviewed the complexities of managing fisheries in a multidisciplinary context, and noted that different tools work in different situations. However, in practice, a well managed fishery should provide *necessary* food (see discussion below about what is necessary and how evaluation of necessity may change with socio-economic status of the country), appropriate coastal jobs and livelihoods, and assurance that environmental damage from resource extraction or methods of obtaining these resources is limited. As discussed above, the ecological and ecosystem effects of fishing to maximum sustainable yield or near equivalents addressed in this management section are large, and the term ‘sustainable’ is not well aligned with the prevention of ecological and environmental damage.

### **Sustainable fisheries and scale**

The concept of a population in ecology is poorly defined. Begon et al. (2006) initially defined a population as ‘consisting of individuals of the same species’. The spatial and temporal scales need to be defined or implied for each study population, and they can be confounded within the marine environment due to planktonic dispersal in most species. Within fisheries, the concept of a ‘stock’ is better defined. A stock is an interbreeding population of fish occupying a particular geographical area where immigration and emigration can be largely ignored (Begg et al., 1999). However, many stocks are managed on an historical and practical basis, and assumptions regarding immigration and emigration are often poorly checked (Begg et al., 1999), despite molecular methods being available for several decades (Pawson and Jennings, 1996; Carvalho and Hauser, 1994).

Fortunately, concept ambiguity is not always the case. For example, the ICES considers cod in the North Sea, eastern English Channel and Skagerrak a ‘stock’ (ICES, 2017), based on evidence of linkages in population structure between these areas (ICES, 1991), which makes the distribution of the stock very large. Counter to this good example of science-informed management is that the fundamental management unit for herring, while divided by spawning season, is for the North Sea, Skagerrak, Kattegat and eastern English Channel (ICES, 2016), despite the multitude of different herring stocks in the North Sea, which have distinct spawning sites but can interact in space and time at other life history stages (Iles and Sinclair, 1982).



The question of scale, however, can be most important when considering not the fish stocks themselves but the scale of the fisheries harvesting these stocks. Smaller vessels generally stay closer to the coast (Tzanatos et al., 2006; Breen et al., 2015; Davies et al., 2018), and although there are no formal international definitions of artisanal fisheries or small-scale coastal fisheries (Davies et al., 2018), fishing only coastal areas (<6 nautical miles) from a large stock, such as North Sea (and eastern English Channel and Skagerrak) cod, is unlikely to have a major effect on the reproductive capacity of the stock (see below for examples of where inshore fishing may be problematic and for potential management solutions).

Such spatial fishing patterns are important. For example, in western Africa, local communities rely on seafood as protein, and locally caught fish are important culturally (Golden et al., 2016; Russell, 2017). Given the lack of robust stock assessment in these countries (Seto et al., 2017), determining catch statistics (i.e., such as monitoring CPUE as discussed above) or the state of the stocks fished by a majority of artisan and nearshore fishers is difficult. However, these same fish stocks have long been targeted by foreign fishers, often operating illegally further offshore (Payne, 1976; Greenpeace, 2015; Seto et al., 2017). For example, Sierra Leone has frequently had well over half of the estimated caught biomass of fish caught by foreign vessels, with 50% of this foreign catch caught illegally in some years (Seto et al., 2017). Furthermore, the locally caught 'artisanal' catch has been consistently under-reported (Seto et al., 2017), making the sustainability of the stock difficult to assess.

In Ghana, similar issues of foreign fishers exist, and surveys of people involved in the fishing industry have indicated that obtaining fish for their families has become more difficult in recent years (Russell, 2017). This lack of fish for their families may be linked to increases in price of fish related to greater demand and hence a greater willingness to sell catches or more fishers fishing the stocks; certainly the increase in price of fish may have driven increases in artisanal landings. While few data exist from Ghana, estimates of artisanal domestic landings in Sierra Leone have increased since 2000 (Seto et al., 2017). The increase in landings could be a sign of healthy fish stocks, but it could also be caused by increased fishing pressure that will subsequently cause a depletion of resources.

Local inshore fisheries can have large effects on some fish species and even on ecosystem function. For example, in coral reef communities, large herbivores, such as many parrotfish, can be key target fishery species, often targeted selectively through spearfishing (Bellwood et al., 2003; Dalzell et al., 2006). Depletion in these fish can result in changes in the competitive balance of coral and algae on the reefs, with algae outcompeting coral and the function of the ecosystem beginning to change (Adam et al., 2011; Holbrook et al., 2016). However, in many of these cases, demand for parrotfish has escalated in recent years, alongside the decline of other larger predatory fish, and exploitation has therefore increased (Madi Moussa, 2010). Also, in some locations, such as the UK, the bulk of inshore fisheries catch is for less mobile species, such

as shellfish including scallops and *Nephrops*, although fin-fish are also caught inshore (Richardson, 2017). Inshore fisheries clearly diminish the populations of these non-mobile species locally, although unfished grounds (on or offshore) can provide larval recruitment to fished areas, demonstrating connectivity of inshore and offshore stock over generations (Bell et al., 2018).

Key to this discussion of the scale of stock and fishing area is that local inshore catches are unlikely to greatly affect the sustainability of a geographically large stock of highly mobile fish, even if they may deplete smaller populations in isolated areas. However, demand for fish has driven larger vessels to exploit fish further from shore. In developing countries, such as those in West Africa, this exploitation can mean that local sources of nutrition are depleted, putting the local human populations at risk. Even in developed countries, larger fishing boats are negatively affecting the historic fishing industry, and many (now former) fishing towns have been hugely affected (Reed et al., 2013). This degree of negative impact raises the question of who are sustainable (or unsustainable) fisheries actually for?

### Who are fish for?

While evidence suggests that early humans foraged in intertidal and shallow subtidal areas, exploitation of marine fish for human consumption required the use of technology, albeit primitive (Marean et al., 2007). The terrestrial/marine divide is important to remember in terms of who fish are for, as for most of human evolution all but the most coastal of species were not available. Fish form an important part of many of the multiple trophic levels found in marine environments (Pauly et al., 1998), and provide food for predatory fish, seabirds and marine mammals, as well as decomposing and scavenging organisms once the fish have died (Dayton et al., 1995).

Arguments about the role of humans in nature suggest that we either dominate the hierarchy or should be considered level with other organisms (Harding, 2009). Sustainability concepts in fisheries related to maximum long-term exploitation of marine ecosystems clearly place humans in the former, dominating role. However, our role in extracting fish has important consequences for the wider marine community. Fishing can have direct effects on other wildlife, such as entanglement in nets and bycatch, as well as indirect effects by reducing food for these non-target species (Cairns, 1987; Dayton et al., 1995; Trites et al., 1997; Tasker et al., 2000; Furness, 2002). The 'sustainable' human take of a fishery, which can be up to 80% of the population's carrying capacity, clearly has an effect on the wider food chain. However, in practice, such changes can be masked by multiple trophic interactions in fish. For example, seabirds tend to feed on small, pelagic, oil-rich fish, the same food source for the larger, more fisheries-targeted predatory fish; unless overfishing is severe, seabirds can be relatively unaffected by it (Furness, 2002). Other examples of marine ecosystem resilience can be found in Dayton et al. (1995), where reduction and extinction of whale populations free up resources for other fish. However, resilient ecosystems can only cope

with so much change, and could ultimately reach tipping points (Jackson et al., 2001; Biggs et al., 2009). As such, understanding that fish play an important role in healthy marine ecosystems is important beyond the sustainable extraction paradigm prevalent in fisheries thinking.

From the human perspective, marine fish and fisheries have played an important part in the lives of many coastal communities the world over (Probyn, 2016). They have provided a cheap and nutritious source of food, especially in terms of oil and protein to many communities (Tacon and Metian, 2013). Fisheries and the associated processing industries have also shaped the economies of many coastal towns and cities worldwide (Reed et al., 2013).

However, from a biological perspective, fish are far from an essential part of a human diet. Research has demonstrated that it is possible to obtain all required nutrients from plant-based diets (Jacobson, 2006; Craig, 2009), and that plant-based diets are more environmentally responsible than those containing animal products (Poore and Nemecek, 2018; but see Hillborn et al., 2018, and discussion on the role of seafood below). Ultimately, eliminating the need for human consumption of any fish could be possible, but would require successful distribution networks for food, changes in western diets, reversal of the trend for increased meat consumption in countries such as China, and massive changes to economic inequity in many parts of the developing world so that they could afford and obtain alternative protein supplies. While all of these changes would be desirable from a biological marine conservation perspective, they are long-term and ultimately unrealistic to achieve in full. In addition, prevention of fishing and consumption of fish would deprive many people of employment, as well as a cultural way of life (Probyn, 2016).

The lack of a strict dietary need for fish (not to be confused with the need for protein, which may be provided most easily by fish in some communities) is, however, worth bearing in mind. Firstly, the fish we consume is typically of a high trophic level (Yodzis, 2001; Spiers et al., 2016). Largely, eating fish would be the only time a typical human consumes the flesh of a predator. Passing biomass and energy between trophic levels is inefficient with typically only 10% passing to the higher level (Pauly and Christensen, 1995). As such, eating predators is inefficient, and especially fish, as fish form one of the major groups of food waste in many societies (Parfitt et al., 2010).

Secondly, the use of many commercially caught fish is inefficient. Over a third of fisheries landings go into aquaculture feed or other non-direct food uses, when plant-based alternatives are available to replace or supplement fish in these feed products (Huntington and Hasan, 2009). These uses of fish in aquaculture mainly come from the offshore fishing industry (Jacquet and Pauly, 2008). From a social perspective, many fishing practices are also inefficient. For example, small-scale inshore fisheries often provide the bulk of employment in coastal areas, as well as the highest value catches, yet can contribute to a far smaller percentage of the overall catch than larger offshore fisheries (Teh and Sumaila, 2013; Davies et al., 2018). Therefore, from the social perspective of employment,

small-scale fisheries may be more efficient in coastal areas, even though economically this efficiency may not be the case. However, large industrial fishing operations in the high seas (outside the exclusive economic zones of individual nations) are often unprofitable without government subsidy, with 54% of high-sea fishing grounds being classified as unprofitable in a recent study (Sala et al., 2018). Furthermore, in many countries, coastal communities, and especially indigenous communities, have been disenfranchised by the commercialisation of fish stocks and allocations of fish quota and believe that they have been ignored in the pursuit of economic progress (McCormack, 2016).

Although these arguments may not fully address who fish are for, they highlight that we need to consider the natural role of fish in marine ecosystems and to 'own' or consume fewer, and lower trophic level fish. The above discussion also begins to indicate that marine fish may be best sourced from maritime (human) communities, and most sustainably sourced at a local level, near to shore. The advantages and disadvantages of such an approach are considered below.

### **Returning to inshore local fisheries to sustainably manage fish**

The proposition that we need to move back to inshore local fisheries to sustainably manage fish is based on my personal interpretation of the information presented above. While others may be able to adopt a different viewpoint based on the same facts and discussion presented, for biological, social and economic reasons, I believe that the movement back to inshore fisheries at a global level is key to the 'sustainability' or preservation of fish, as well as associated livelihoods and culture. The proposition is based largely on the consideration of mobile finfish populations where the stock (and management of stock) covers a large geographical range only part of which falls in coastal regions. As discussed below, it does not mean complete removal of all quota systems or unrestricted capacity of the inshore or artisanal fleets, and other important conservation measures such as establishing marine protected areas (MPA) could still be utilised in inshore waters. That full adoption of the recommendations is very unlikely to occur is appreciated; however, movement towards re-establishing inshore fishing, at the expense of (rather than in addition to) subsidised and damaging offshore practices, would be a step forward for truly sustainable use of the oceans' living resources. The proposed return to inshore local fisheries, although more ambitious, is similar in many ways to the proposed 30% target for marine reserves, with fisheries control measures for the remaining 70% of the ocean (O'Leary et al., 2016). The advantages and disadvantages of the move to local fisheries are provided in the remaining sections.

#### **Advantage 1 – enhanced stock sizes**

As discussed above, coastal fisheries with smaller boats, typically considered 'artisanal' fisheries, are unlikely to be able to fish the entirety of a stock covering a large geographical area, even if the current definitions of 'inshore'

were extended to beyond 6 nautical miles. Based on simulation studies of large marine reserves, large protected areas have been found to both conserve mobile stocks with a diverse range of movement patterns and provide increased catches of these stocks outside the boundaries of the reserves (Cornejo-Donoso et al., 2017). As such, the large offshore area would act as an effective marine reserve, allowing movement of fish into inshore waters where they could be caught. While restricting fishing only to inshore waters would not maximise the catch of fish (which would require designating around 30% of total ocean as marine reserves), it would greatly enhance the stock sizes (Cornejo-Donoso et al., 2017) and therefore limit the environmental harm of excessive reduction in fish populations to well below carrying capacity.

As larger vessels were prevented from fishing further out to sea, the often limited quota on inshore vessels could be increased, though the increase need not be as great as the removal from offshore quota (as discussed below). The implementation of such a policy focused on inshore fishing should ensure that the reproductive potential of the fish stocks remains high, as the majority of the population of the stock would be off limits to fishers at any given time. Large, offshore MPAs (created by default here) have been shown to be effective in managing even highly mobile species (Le Quesne and Codling, 2009) and ensuring ecosystem function by ensuring protection for predatory species (Cinner et al., 2018).

Some potential ecological issues with such an approach, however, would need further regulation. Coastal waters can contain many important habitats, such as coral reefs or seagrass, as well as spawning aggregations at particular times of year. Many of these areas would need to be designated as marine protected areas, likely with restrictions on certain species (i.e., keystone coral reef species such as parrotfish), gear types (i.e., bottom trawling in sensitive habitats) or overall catches in these important areas (McClanahan et al., 2002). Species with very coastal distributions, either permanently or seasonally, may also need to be protected through catch or effort management, or use of selective fishing gears. Species such as shellfish, which show limited mobility as adults, may also need more conventional 'quota' management measures to prevent excessively heavy fishing of these areas. However, even for non-mobile species, recruitment of larvae from unfished offshore areas would provide increased levels of stock enhancement inshore (Bell et al., 2018), meaning that the same commercial value could be obtained from fishing a smaller proportion of the overall population size. Such an approach is evidenced from studies showing enhanced larval recruitment from MPAs (e.g., Pelc et al., 2009).

### **Advantage 2 – enhanced economic efficiency**

While large-scale industrial and commercial fishing may help contribute to gross domestic product and economic growth, in practice, the large subsidies paid primarily to offshore fishing (Jacquet and Pauly, 2008) mean that the process is not economically sound in many cases (Pauly et al., 2002; Sumaila et al., 2007; Sala et al., 2018, spe-

cifically in consideration of offshore fishing in the high seas). However, removal of such subsidies by individual states creates an uneven playing field and political discontent, unless the process can be managed internationally (Sumaila et al., 2007).

Fisheries also face other economic issues, beyond simple 'cost per tonne of fish' metrics, which apply equally in many countries worldwide. Locally caught fish have a higher value to the fisher, for example, when sold directly or locally to fishmongers or local restaurants (Carpio and Isengildina-Massa, 2009; Bloom and Hinrichs, 2011), the latter of which can also bring tourist money into fishing towns (Everett, 2008). Even with the small quota shares, local, inshore fisheries employ the bulk of the coastal fishing industry (Teh and Sumaila, 2013), providing skilled jobs in areas of otherwise high unemployment or poverty (Reed et al., 2013).

Finally, locally caught fish are likely to use fewer resources, such as diesel fuel, to catch fish (Jacquet and Pauly, 2008). In a recent study, energy use in small pelagic fisheries (which are normally coastal) was far lower than in other capture fishing methods, and the carbon and energy needed to capture small pelagic fish was less per gram of protein in the human diet than plant-based (e.g., vegan) diets (Hilborn et al., 2018).

### **Advantage 3 – preserved cultural values**

Fish form an important part of the coastal heritage of many towns and cities, and the closures of small-scale inshore fisheries have resulted in much deprivation in many towns in the western world (Reed et al., 2013). Local fisheries create employment, as discussed above, but also preserve the cultural values of towns and the people who live in them. These cultural values can attract further economic incentives, such as tourism; for example, Padstow in the UK has a vibrant tourism industry, based around fishing and seafood (Howard and Pinder, 2003; Busby et al., 2013).

Cultural values associated with fishing can also extend beyond catching fish. Maritime culture can be preserved in towns with reduced levels of fishing (e.g., Jones et al., 2014) and can also lead to new seafood production methods. Local mollusc aquaculture (oysters or mussels) in sheltered bays, harbours and estuaries can provide many of the cultural values and employment prospects of the fishing industry, as well as producing a high value product with low carbon emissions and potentially positive effects on pollution levels (Hilborn et al., 2018).

### **Advantage 4 – enhanced local governance**

Local governance systems for fisheries have had demonstrated successes in the past (Pinkerton and Weinstein, 1995; Blyth et al., 2002; Townsend et al., 2008). They can provide an alternative to top-down regulated approaches common in fisheries management. Even rights-based systems such as individual transferable quotas, although demonstrated to prevent fisheries collapse by limiting processes such as discarding (Costello et al., 2008), remove local decision-making to a central decision on total allowable catch which creates resentment among

fishers (McCormack, 2016). While removal or restriction of fishing rights to those currently practicing offshore fishing will also cause resentment in those affected by these closures, the increase in value of fish and increase in profitability of inshore fishing, of which the majority of the number of fishers partake, should provide a good foundation for successful local governance.

Traditional fishing techniques, especially by indigenous populations, have allowed decisions to be made locally about the local abundance of catches. For example, in Papua New Guinea, areas are closed to fishing except for specific festivals, which has resulted in conservation benefits for these areas (Cinner et al., 2005). Many other indigenous techniques have been documented throughout the world (Johannes, 1978; Colding and Folke, 2001), and include area closures when catches begin to decline and seasonal closures or seasonal restrictions on breeding species (Johannes, 1978).

Local understanding and agreement between fishers, especially when closing sites or switching target species, will not happen with races to reach quota limits. Instead, local understanding allows for concepts such as self-policing on a local scale, ensuring that all fishers adhere to a common set of unwritten rules. Such local self-policing has been effective in establishing successful marine protected areas (Taylor et al., 2013; Islam et al., 2017), and could be similarly effective in local fishing.

Local governance can go beyond the fishers themselves. Local seafood industries, from fish processing to seafood restaurants, could ensure markets for locally caught fish that are locally abundant, rather than relying on specific species. Conservation organisations could use catches to demonstrate the local diversity of marine life and help generate interest in the marine environment, lacking in many countries (Vincent, 2011; Jefferson et al., 2014).

### **Disadvantage 1 – fewer fish to sell**

The obvious disadvantage of any reduction in fish catch is fewer fish to sell. However, it is perhaps time to consider that wild-caught fish, especially in the western world, be treated as a luxury item rather than a necessity (Balmford et al., 2002). Many fish, especially from offshore fishing, are used in animal food (including food for aquaculture, pet food, livestock food, etc.; see Alder and Pauly, 2006), and many processes such as tinning or processing of fish do not equate to how we treat wild-caught terrestrial animals as food. Removing this wasteful practice and treating wild-caught fish with the respect afforded even pseudo-wild meat such as farmed venison or wild boar would create less concern about the amount of fish available to sell.

In addition, targeting lower trophic level fish (while ensuring food supplies are large enough for the predators) or filter-feeding shellfish (especially from mollusc aquaculture) may allow a greater biomass of fish and seafood to be caught or produced in a sustainable manner (Zhou et al., 2015; Hilborn et al., 2018; but see warnings of overfishing low-trophic level fish in Smith et al., 2011). Important to remember is that fish are necessary for healthy human diets in parts of the developing world. As indicated above, however, along the coast of Africa (and

replicated in many developing countries), a large part (~50%) of the catch is taken by offshore foreign fishing operations. As such, there may not be fewer fish, but more fish, available to these local communities if offshore fishing were halted or reduced.

### **Disadvantage 2 – rising price of fish**

If market forces were left unchecked, and the supply of fish reduced (along with government subsidies for fishing), the price of fish would likely increase. To some extent, this argument follows from the one above, and is correct if fish are to be treated as premium food products. As indicated previously, a higher value is often placed on fish caught locally by inshore fishers, which helps to provide the economic boost currently needed for the inshore fleet to survive.

A potential downside can occur from an increase in fish price, however. A higher price may mean that fish are moved from local fishing communities to more affluent urban areas. This move could have one of two effects. Firstly, in developing countries, local communities could face shortages in fish to feed their families (see example of Ghana above, where there are fewer fish locally despite increases in the inshore catch; Russell, 2017). Secondly, in more developed countries, the maritime culture of a fishing town with no affordable fish is likely to cause social discontent (see discussion of potential solutions in Loring et al., 2016). Both of these processes might lead to increases in illegal or unreported fishing, beyond allocated quotas.

To mitigate against such increases there may be several solutions. Firstly, government subsidies could be applied; not as present on the catch of fish, but on the sale of fish locally, meaning that selling locally would ensure that fishers and those in the fishing industry obtain the same benefits as selling to more affluent urban areas. These subsidies would provide both environmental and social benefits to deprived areas, and hence be very different to the current subsidies given to the offshore fishing industry. A second, more controversial approach may be the adoption of a universal basic income for all citizens (Perkiö, 2015). This approach may be especially important in the developing world, as fishing then becomes a way of directly feeding family or wider community, rather than a means of making a living.

### **Disadvantage 3 – human health effects**

Many dietary studies have indicated the benefits of fish, especially oily fish, in the human diet (e.g., Ruxton, 2004). As discussed above, one can live perfectly well on a plant-based diet that excludes meat, dairy and fish (Craig, 2009). While fish can provide high levels of many nutrients, a typical western diet can readily compensate for the consumption of fewer fish.

Health effects may be more important in the developing world, however, and particularly in communities that currently rely on fish for dietary needs such as protein. Policies would need to be in place to ensure that enough local catch stays in these communities (see above) to avoid a decrease in the amount of fish to consume locally.



Also worth considering are the potential health benefits of reducing fish consumption. Bioaccumulation of toxic pollutants in high-trophic level fish such as tuna and swordfish can provide serious health risks to those who consume them (Streit, 1998). Also, microplastics have been found in many seafoods, and are likely to accumulate in higher trophic level animals (Griffin et al., 2018; Li et al., 2018), although the human health risks of consuming microplastics are largely unknown (Anon, 2017).

#### Disadvantage 4 – not eating what is produced locally

While not true of all countries, in areas of Northern Europe and especially the UK, locally produced fish are not eaten locally. The UK is a net exporter of fish, even as it also imports large quantities of whitefish such as cod, as well as tuna, salmon and warm water prawns (Seafish, 2018). The inshore catches, which can include flatfish and shellfish such as clams and scallops, are exported to southern Europe (Seafish, 2018). For local inshore fisheries to work as proposed here, local markets need to be created to maximise the economic value of fresh, local fish as a premium product (Balmford et al., 2002; Loring et al., 2016).

Much of the discrepancy between catch and consumption is historic, based on proportionally larger catches of whitefish, such as cod and haddock landing in UK ports, and the industrialised process of food production (e.g., in fish ‘fingers’ and other processed forms of fish), based on currently imported cod and other gadoids. The suggested removal of fishing from offshore waters would mean that the proportion of whitefish is likely to increase in coastal catches again. However, local markets do need to exist for the dominant species catches. While research indicates that most consumers cannot differentiate between most white-fleshed fish species (Hamilton and Bennett, 1983), further behavioural change would be needed in the UK to shift diets away from traditional British fish, often served in batter, to new experiences such as shellfish.

#### Conclusions

Whether successfully achieved or not, trying to manage fish on a concept of biological sustainability under current economic and political systems produces major ecological and social problems. Sustainable fishing in its current form is a broken concept. The proposal outlined above to limit fishing solely to inshore waters is radical, helps to break the concept of a global fishing industry, and provides opportunity (and admittedly challenges) of consider wild resources such as fish in a new light. Alongside other marine conservation measures such as MPAs, this approach could provide a good solution, ecologically, socially and economically (given the need for subsidies to ensure viability of much fishing), essentially achieving the goals that sustainable fishing should be providing, and aligning with new economic thinking about ensuring social benefits while maintaining fishing levels within safe ecological boundaries (Pauly, 2006; Raworth, 2017). The more natural marine ecosystems that would result as a consequence of this proposal (i.e., not removing up to 80% of carrying capacity of fish to

create maximum sustainability) would also help with beneficial ecosystem functions, such as limiting CO<sub>2</sub> production, and ensure that many fish remain where they need to be for resilient marine ecosystems in the face of climate change. While the proposal as outlined is supported by academic literature, it clearly needs further multidisciplinary study into the socio-economic and socio-ecological implications. However, such a radical change will clearly take time to occur. Gradual shifting of quota from offshore fisheries to lower biomass and inshore fisheries to higher value catches would allow for empirical tests of the assumptions that lead to many of the benefits described above.

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#### Competing interests

The author has no competing interests to declare.

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