



## Ghoti

### Ghoti papers

Ghoti aims to serve as a forum for stimulating and pertinent ideas. Ghoti publishes succinct commentary and opinion that addresses important areas in fish and fisheries science. Ghoti contributions will be innovative and have a perspective that may lead to fresh and productive insight of concepts, issues and research agendas. All Ghoti contributions will be selected by the editors and peer-reviewed.



### Etymology of Ghoti

George Bernard Shaw (1856–1950), polymath, playwright, Nobel Prize winner and the most prolific letter writer in history, was an advocate of English spelling reform. He was reportedly fond of pointing out its absurdities by proving that 'fish' could be spelt 'ghoti'. That is: 'gh' as in 'rough', 'o' as in 'women' and 'ti' as in palatial.

## Ending overfishing while catching more fish

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### Abstract

The world's seas and oceans are a vital source of animal protein from fishing and a major contributor to global food security. It has been argued that global wild-catch production has reached its limit, and there is concern that many species are overfished. Concerns are also mounting about the state of marine ecosystems and the ecological impacts of fishing on them, with increasing efforts to protect marine biodiversity. Fisheries appear to be at an impasse – demand for seafood is rising but so is concern about the impacts of fishing. However, through a simple analysis, we show that global exploitation rates are well below long-term sustainable levels at a whole ecosystem level. The oceans can support considerably higher sustainable catch than currently harvested. Overfishing has happened but only to a small fraction of species as a result of intensive and selective fishing. Shifting fishing effort away from highly targeted stocks towards currently underutilized species would reduce pressure on overfished species, result in fewer adverse ecosystem effects of fishing and increase overall fisheries production. This shift requires significant changes to our views about seafood, particularly in the developed world. We

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suggest ways in which this paradigm shift could happen and the range of expertise that would be required to achieve higher global yields with less ecological impact.

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### Status of global fisheries and marine ecosystems

World capture fisheries production has been relatively stable for the past decade (FAO 2012). Global landings of marine species (excluding plants) fluctuated between  $7.77$  and  $8.04 \times 10^7$  t from 2006 to 2011, with additional discards estimated at about  $7.3 \times 10^6$  t (Kelleher 2005). It has been argued that global catch limits have been reached (e.g. Chassot *et al.* 2010; Worm and Branch 2012). However, fishing effort worldwide continues to increase. A global data set of fishing effort reveals that fishing power has increased by an average of 10-fold globally and 25-fold for Asia since the 1950s (Watson *et al.* 2012), although effort in some developed countries has declined in recent years. The stagnation in catch with increase in effort has resulted in a decline in catch-per-unit-effort, suggesting continuing decline in abundance of traditionally harvested species as well as major economic inefficiencies.

In addition to biomass reduction in target species, fishing clearly has ecological impacts on harvested species and on marine ecosystems as a whole (Botsford *et al.* 1997; Murawski 2000). Many commercially harvested fish stocks have been overfished, and overfishing continues for certain stocks (Worm *et al.* 2009; Costello *et al.* 2012). Selectively catching a specific ecological group generally reduces the abundance of that group in relation to unfished groups. This common-sense conclusion is supported by considerable evidence that biomass of large fish, top predators and highly valued species has declined substantially, whereas smaller fish and species with low economic value have changed less or even increased (Benoît and Swain 2008; Richardson *et al.* 2009; Stone 2010; Collette *et al.* 2011), even though the serial addition of low-trophic-level fisheries may have occurred (Essington *et al.* 2006). Furthermore, the incidence of stock collapse has been higher for species that experienced greater relative fishing mortality (the ratio between the

instantaneous fishing mortality  $F$  and reference point  $F_{msy}$ ) and a longer history of fishing (Pinsky *et al.* 2011). These findings suggest that there will be an ongoing trend towards fewer fish of species that are heavily exploited but more of species that are lightly harvested and low-valued, resulting in further changes to the structure of marine ecosystems under current fishing patterns.

Changes in the structure of marine ecosystems in turn have consequences for harvested species. Fishing can alter interactions between groups through reduced competition for lightly fished groups or increased *per capita* predation on heavily fished groups, resulting in further depression of the highly fished populations (Daan *et al.* 2005; Zhou 2008). For example, high selective fishing pressure on cod and flounders may have increased abundance of dogfish and skates on Georges Bank because the dietary overlaps between cod–dogfish and flounders–skates are generally high (Murawski and Idoine 1992). This can cause the carrying capacity of heavily harvested species to shrink as a result of their niche being reduced by competitors. The reduction in abundance and distribution range of a species by fishing allows less impacted species to colonize the range formerly occupied by the highly impacted species (Bundy 2001; Planque *et al.* 2010). Moreover, the lack of recovery of some overfished stocks has been attributed to changes in life-history parameters and altered interspecific interactions caused by past fishing pressure (Hutchings and Reynolds 2004; Wijk *et al.* 2013).

### Global marine potential in food production

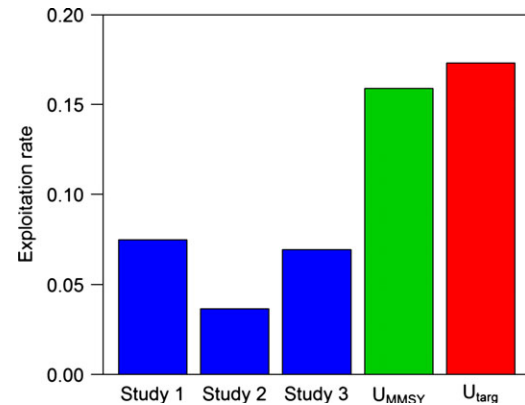
Research on overfishing has largely focused on target species. The status and roles of the entire marine fish community have received little consideration in the debate about overfishing. For finfish alone, among more than 16 700 validated fish species in the oceans (CoML 2010) only about 1000 species are recorded in FAO Fishery Statistics of various sorts. Apparently, <10% of marine

fish species are targeted, and <3% of them are overfished (based on FAO's classification that <30% of target species are overfished, FAO 2012). Estimates of fishing mortality on non-target species are rare. However, in two Australian fisheries where assessments of all fish by-catch species were undertaken, incidental relative fishing mortality (i.e.  $F/F_{msy}$ ) for non-target species was generally much lower than for target species (Zhou *et al.* 2009, 2011).

We gathered data from several studies and FAO reports to explore the global marine potential in fisheries production, focusing on finfish and ignoring marine plants, invertebrates, reptiles and mammals due to a lack of data for these groups in the studies we cited below. We asked two hypothetical questions:

1. Considering all the fish in the ocean, what is the overall aggregate exploitation rate at recent catch levels?
2. Is this overall exploitation rate sustainable?

We refer to three studies that provide global fish biomass estimates. Jennings *et al.* (2008) combined macroecology, life-history theory and food web ecology to predict marine fish biomass and production. They estimated global fish biomass to be  $8.99 \times 10^8$  t. Wilson *et al.* (2009) used 84 ecosystem models worldwide and estimated the total teleost biomass in the oceans to be  $2.05 \times 10^9$  t. Tremblay-Boyer *et al.* (2011) estimated biomass using an ecosystem model representing ecosystems as a function of energy fluxes through trophic levels. Their model results in a total biomass of  $1.08 \times 10^9$  t for predators (trophic level  $\geq 3.5$ ). For an estimate of total catch, FAO (2012) reported that marine fish landings average  $6.77 \times 10^7$  t. Adding estimated annual discards (Kelleher 2005 2) gives an estimate of  $7.5 \times 10^7$  t of catch of both teleosts and elasmobranchs. Based on these studies, the overall exploitation rate ( $U = \text{catch}/\text{biomass}$ ; note the estimated biomass tends to be an average over a year so the ratio is not exactly an exploitation rate) is about 0.075, 0.037 and  $0.069 \text{ y}^{-1}$ , respectively, for each biomass study (Fig. 1). These are very coarse estimates and are likely to be overestimated. For example, Tremblay-Boyer *et al.* (2011) note that the global biomass of mesopelagic fishes alone was approximately  $1 \times 10^9$  t, indicating that the biomass estimate of Jennings *et al.* may be too low. Furthermore, the Wilson *et al.* biomass estimate is for teleosts only, but the catch includes elasmobranchs, and the Tremblay-Boyer *et al.* biomass is for predators only while current catches include species at a trophic level  $< 3.5$ .



**Figure 1** Comparison of approximate exploitation rates from different studies and sustainable reference point. Studies 1, 2 and 3 are the ratio of global marine fish catch (retained catch plus discards) to (1) the total global marine fish biomass from Jennings *et al.* (2008), (2) the global marine teleost biomass from Wilson *et al.* (2009) and (3) the biomass of global marine predators at or above trophic level 3.5 from Tremblay-Boyer *et al.* (2011). Catch and discards data are from FAO reports.  $U_{MMSY}$  is the multispecies exploitation rate at maximum sustainable yield for target species, and  $U_{target}$  is the average exploitation rate for target species from 10 marine ecosystems, both from Worm *et al.* (2009).

branches, and the Tremblay-Boyer *et al.* biomass is for predators only while current catches include species at a trophic level  $< 3.5$ .

Nevertheless, our estimated exploitation rates can be roughly compared with the mean ecosystem-level exploitation rate at maximum sustainable yield ( $U_{MMSY}$ ) of 0.16 and of about 0.17 for target species only (Worm *et al.* 2009). If these numbers are approximately correct, current overall fishing mortality rates are clearly sustainable (although individual species could be subject to overfishing). Similarly, using the estimated global fish biomass and  $U_{MMSY}$  from the three studies, we can obtain potential multispecies maximum sustainable yield at ecosystem level (MMSY) of approximately  $14.4 \times 10^7$  t,  $32.8 \times 10^7$  t and  $17.3 \times 10^7$  t, considerably higher sustainable catch than currently harvested. Moreover, the reference point  $U_{MMSY}$  could be higher than 0.16 if catch included more species at lower trophic levels because of their higher productivity. Besides abundant groups such as mesopelagic fish and invertebrates, numerous mixed species that are currently avoided or discarded as by-catch could contribute to a significant increase in sustainable yield (Venugopal *et al.* 1995; Shahidi 2006). The

problem is that the existing exploitation rates are concentrated on a relatively small number of targeted species, particularly on more economically valuable groups at higher trophic levels.

### The root of overfishing

High fishing intensity has been identified repeatedly as the single foremost culprit causing global overfishing (e.g. Worm *et al.* 2009; Watson *et al.* 2012). However, the low overall fishing mortality rate at an ecosystem level and a limited proportion of overfished stocks suggest that fishing pressure alone is only a part of the problem. Rather, the root of the problem is selectively harvesting only certain target groups from the ecosystem, whether by species, stock, size or sex (Zhou *et al.* 2010). In fact, by definition, what is common among the three types of overfishing, recruitment, growth, and ecological overfishing (see Murawski 2000), is selectively catching too many fish of a certain type, size or sex, either within a species or a community. In developed countries, this problem is largely driven by commercial fisheries that often strive for a short-term (years to decades) economic profit rather than for sustainable food security (Sethi *et al.* 2010).

### A solution to end overfishing while securing food production

While there have been some successes in reducing overfishing (Worm *et al.* 2009), attempts to reduce global fishing capacity have so far proved fruitless except for a small reduction within some developed countries. As the fundamental goals are to achieve global food security while minimizing fishing induced changes in the structure and function of marine ecosystems (Rice 2013), an obvious resolution is to redistribute fishing pressure to a wider range of ecosystem components through balanced harvesting (Zhou *et al.* 2010; Garcia *et al.* 2012). The concept is to distribute moderate fishing pressure to all ecosystem components in proportion to each component's natural productivity. This requires a selectivity pattern at the ecosystem level that is different from the current one in most world fisheries. This also implies a need for spatial balance in exploitation (Worm and Branch 2012). Furthermore, the proposed approach applies equally to species at low trophic levels, as relative fishing mortality may have been

too high for some forage species (Pinsky *et al.* 2011; Smith *et al.* 2011). For overfished stocks, reducing or temporarily ceasing direct targeted fishing mortality and only allowing acceptable incidental catch could hasten recovery (Neubauer *et al.* 2013). When diverse components are proportionally and sustainably exploited from an ecosystem, overfishing, including ecological overfishing, will be avoided, the impact on community structure and ecological function will be minimized, and the total fishery production will increase (Rochet *et al.* 2011; Garcia *et al.* 2012; Law *et al.* 2012).

### Beyond fishery science and management

Fisheries are vital to the livelihoods of millions of people around the world (FAO 2012). Compared with other forms of food production, fisheries generally have less environmental impacts, for example fisheries produce less greenhouse gases, use less freshwater and do not directly use fertilizers, insecticides or herbicides (Vries and Boer 2010; Hilborn 2013; Kearney 2013). From both conservation and food security perspectives, neither overfishing nor under-fishing is desirable. Underutilization of renewable natural resources is a loss to human society; disproportionately high abundance of less-fished species may depress competitors and other heavily fished species. Lower production of animal protein from the sea will also shift the pressure elsewhere, with greater impact on terrestrial ecosystems (Hilborn 2013; Kearney 2013). Therefore, it is desirable to end overfishing and simultaneously catch more fish through the balanced harvest approach.

Although the proposed solution of balanced harvest would meet these goals, implementing the solution will also undoubtedly encounter technical, political, economic, cultural and ethical obstacles. Balanced harvest provides a direction for fishery management, rather than a precise destination. Solving overfishing so far has been largely dealt with by fisheries managers, fishers and scientists focused on single species or limited species groups. The proposed solution will only be feasible with much more diverse inputs, including from educators, politicians, researchers, conservation groups, media, consumers and the food industry because the demand for seafood products is driven by consumer interests, including tastes and cultural values about what should or should not be



harvested or eaten. In particular, education about these issues through various means will be important so that our next generation can make more considered judgments when they choose seafood.

There are many ways that science and technology can contribute to the shift to the balanced harvest approach. Fisheries scientists can recast harvest models to coincide with the marine ecosystem of interest and include all relevant species that could be harvested by each type of fishing gear. Much of the research on gear technology so far has aimed at increasing selectivity to reduce by-catch. To end overfishing and increase production, advances in fishing strategy and gear technology can be directed towards harvesting ecological components according to their biomass and productivity, instead of focusing on avoiding by-catch of non-target components unless they are vulnerable.

Fisheries economists have investigated a range of instruments that support or hinder fisheries management. For example, subsidies to fisheries are immense and have contributed to global overfishing (Sumaila *et al.* 2010). Under a balanced harvest policy, governments could consider stopping subsidies for fisheries that disproportionately catch high-valued but low-productivity or low-abundance components. Arguably, it may be preferable to impose levies on catching such components to create disincentives. Initially, existing subsidies could be transferred to provide incentives for fishing and processing low-valued, high-production components. This is another field where economists can contribute to ecological sustainability and food security debates. Changing fishery behaviour through appropriate incentives has been shown to be more effective than reducing capacity through mechanisms such as buybacks (Clark *et al.* 2004).

Catching currently low-valued components (e.g. mixed-species and mesopelagic fishes, see Catul *et al.* 2011) may not be economically viable under today's social and economic circumstances, particularly in developed countries. Adding value to these components, through product development and marketing (Venugopal *et al.* 1995), would help to achieve the dual goals of protecting the marine ecosystem while increasing the total food production.

The transition to utilizing underused species for food is not unrealistic, as in many countries nearly all fishes are consumed directly and indirectly as food. To most people, eating fish, even if it is not a currently preferred food item, is likely

more acceptable than entomophagy, which promotes insects for future food (Huis *et al.* 2013). Cultural exchange and development of seafood processing techniques can play an important role in influencing people's dining habits. One example of how non-traditional seafood items can easily gain acceptance is the rapid increase in the popularity of sushi and sashimi in the west. Recently, a well-known restaurateur has gained a strong following in USA by serving sustainable sushi including sushi made with invasive species instead of species that are overfished (<http://miyassushi.com/about-bun-lai/>, accessed on 28 November 2013). Media, educators and retailers can raise public awareness about the problems of selective overfishing and the benefits of balanced harvesting and help guide consumers towards sustainable seafood choice. That the public is interested in seafood sustainability, and alternative seafood choices, is evidenced by the rising popularity of chefs like Barton Seaver (2011) who, for example, recommends decreasing the amount of higher trophic level fish in people's diets in favour of lower trophic level species. As consumer demand increases for non-traditional seafood, public pressure will help to move fisheries management towards more balanced fisheries harvests.

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