# Ecosystem-based fisheries management requires a change to the selective fishing philosophy

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**Globally, many fish species are overexploited, and many stocks have collapsed. This crisis, along with increasing concerns over flow-on effects on ecosystems, has caused a reevaluation of traditional fisheries management practices, and a new ecosystem-based fisheries management (EBFM) paradigm has emerged. As part of this approach, selective fishing is widely encouraged in the belief that nonselective fishing has many adverse impacts. In particular, incidental bycatch is seen as wasteful and a negative feature of fishing, and methods to reduce bycatch are implemented in many fisheries. However, recent advances in fishery science and ecology suggest that a selective approach may also result in undesirable impacts both to fisheries and marine ecosystems. Selective fishing applies one or more of the "6-S" selections: species, stock, size, sex, season, and space. However, selective fishing alters biodiversity, which in turn changes ecosystem functioning and may affect fisheries production, hindering rather than helping achieve the goals of EBFM. We argue here that a "balanced exploitation" approach might alleviate many of the ecological effects of fishing by avoiding intensive removal of particular components of the ecosystem, while still supporting sustainable fisheries. This concept may require reducing exploitation rates on certain target species or groups to protect vulnerable components of the ecosystem. Benefits to society could be maintained or even increased because a greater proportion of the entire suite of harvested species is used.**

balanced exploitation | biodiversity | sustainability | bycatch | 6-S selection

Ecosystem-based fishery management (EBFM), also referred to as an ecosystem approach to fisheries (EAF), has been proposed as a more effective and holistic approach for managing world fisheries (1, 2). The aim is to sustain healthy marine ecosystems and the fisheries they support by addressing some of the unintended consequences of fishing, such as habitat destruction, incidental mortality of non-target species, and changes in the structure and function of ecosystems (2). EAF requires that fisheries should be managed to limit their impact on the ecosystem to the extent possible. This and similar considerations in EBFM have encouraged more selective fishing. There are several rationales behind the idea of selective fishing, including reducing waste associated with discarding, reducing impacts on protected species such as turtles, marine mammals, and seabirds, minimizing impacts on juvenile fish or bycatch species that play important roles in the ecosystem, and concerns about the trophic impacts of discarding that encourages scavengers (1, 2). To achieve more selective fishing, fisheries management uses one or more of the "6-S" selection strategies: on species, stock, size, sex, season, and space. Reviewing recent advances in fishery science and ecology, we see a paradox in the conventional wisdom that suggests that selective fishing has fewer ecological impacts. We argue here that the 6-S selections may be exacerbating rather than reducing the impact of fisheries on marine ecosystems, in turn negatively impacting the productive capacity of such systems to sustain catches. As an alternative, a "balanced exploitation" approach is discussed to help achieve EBFM.

## EBFM Objectives and Ecosystem Effects of Fishing

EBFM generally has two key goals: conserving the structure, diversity, and functioning of ecosystems; and satisfying societal and human needs for food and economic benefits (1). These two goals have tended to diverge into separate perspectives that have been viewed as often conflicting (3, 4), with selective fishing often proposed as part of the resolution to the conflict (1, 2).

In synthesizing findings from an international symposium on EBFM, Gislason et al. (5) suggested that the ecosystem goal of the EBFM approach is to maintain ecosystem, species and genetic diversity, including directly impacted species, ecologically dependent species, as well as trophic level balance. Their review clearly and concisely captures the ecological objectives of EBFM, which have also been stated in different ways by others (1, 2, 5, 6). These objectives can be summarized succinctly as maintaining biodiversity in aquatic ecosystems.

We consider biodiversity as the variation of all life forms at three levels: genetic, species, and community (7). Biodiversity has three broad measurable aspects: richness, evenness, and phenotypic variation (8), each of which embraces various biodiversity properties that can be quantified using ecological indicators (9–11). For example, richness may include taxonomic and genetic diversity. Evenness may be quantified in several ways, including the species evenness index, size spectra curves, sex ratios, K-dominance curves, ratios among ecological components, and age structure. Phenotypic variation refers to variability in aspects such as body size, life span, body form, diet, growth rate, maturity, and behavior (7).

It is impossible to fish without impacting biodiversity. Overfishing of large vertebrates and shellfish has long been recognized as a leading environmental and socioeconomic problem in the marine realm that has reduced biodiversity and modified ecosystem functioning (12, 13). However, the effects of selective fishing have largely been overlooked given the focus on overharvesting. We argue that it is essential to simultaneously address both fishing intensity and selectivity to achieve EBFM goals. Fishing mortality rates on impacted species (target or

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bycatch) should be reasonably low compared with their productivity to ensure that harvesting is ecologically sustainable. Combined with less selective fishing it is possible to fish without impacting biodiversity to the extent that ecosystem structure and function is compromised, while maintaining the productive capacity of resources to sustain acceptable catches. In this article, we focus on the effects of selective fishing rather than on those of overall fishing intensity. We now explore some of the ways selective fishing impacts biodiversity and fisheries.

## Impacts of 6-S Selection on Biodiversity and Fisheries

Fishing is by nature a highly selective process. Fishers intentionally target particular species and specific components of populations during certain times of the year in selected areas to maximize short-term catch rates and profitability. The expected selectivity is commonly intensified by management regulations and environmental policies. However, selective fishing imposes many ecological effects that may compromise EBFM objectives. It immediately alters the ecosystem by killing and removing certain components, thereby reducing the abundance of certain groups and changing the relative abundance of species, size distributions, and sex ratios, which implies modifications to food web and ecosystem structure, and hence some properties of biodiversity. Altering ecosystem structure can in turn result in changes to ecosystem function including energy flow, element recycling, species interactions, productivity, and resilience. Changes to ecosystem function may then affect sustainability of fisheries. These consequences alone could be defined as ecosystem overfishing (2, 14). In considering the effects of selective fishing, it should be kept in mind that the adverse impacts will be more severe with increasing fishing pressure (15). Selective fishing may have negative impacts on biodiversity and fisheries at low fishing intensity, although the impacts will be less significant and more difficult to detect because other factors and natural population variation may mask the negative effects of selection. Current fishing practices can be characterized as one or more of the following 6-S selections, each of which has been shown to have at least some negative impacts on biodiversity and usually on fisheries production.

**Species Selection.** Regulations on fishing gear to reduce bycatch and technological developments to increase the catch of target species can both have profound impacts on ecosystems. For example, excessive bycatch reduction may have adverse impacts on the economic viability of fishing and on the ecosystem (16). Although the extreme situation whereby fisheries reduce species richness by driving the target species to extinction is uncommon (17), selective fishing results in target and nontarget species being killed disproportionately to their abundances, roles in natural assemblages, and their intrinsic capacities to sustain impacts. Such disproportionate removal can result in changes in biodiversity by altering species evenness, whether increasing it or decreasing it. Recent research on microbial communities reveals that evenness is a key factor in preserving the functional stability of an ecosystem (18, 19), and it is likely that this is a general ecological principle. Ecosystem structure, species relationships and dependencies, and ecosystem processes and productivities can also be impacted (20). Reduced populations of the target species can then suffer increased "natural" mortality by predation from nontarget species at higher trophic levels and reduced carrying capacity through competition with nontarget species at similar trophic levels (16). The former consequence may be explained simply by an increase in the probability of prey–predator encounter. The latter consequence can result from increased abundance of competitive species occupying the niche made available by species removal (21). Although the environmental carrying capacity for all species may remain the same, the resource/capacity available to species whose population is constantly removed will be reduced. A recent simulation study (22) shows that selectively targeting a subset of species can destabilize the food web, whereas unselective fishing does not. This study found that for similar levels of catches, diversity and biomass in the system were always higher when fishing all species nonselectively rather than fishing on a smaller group of target species (22). This research does not necessarily mean that increases in biodiversity due to fishing are always beneficial. For example, fishing can increase evenness and hence that measure of biodiversity because it reduces the abundance of dominant species (23, 24). The key point is to minimize fishing impacts on natural diversity to the extent possible because different ecosystem components sustain different ecosystem processes.

**Stock Selection.** It is not uncommon that some stocks of a species suffer higher fishing mortality than others (25–27). This may arise because some stocks are easier to access (e.g., closer to ports). Management regulations may also intensify stock selection by restricting fishing to certain areas during specific seasons. We recognize that in some fisheries one of the objectives of using spatial and seasonal closures is to protect unproductive or depleted stocks (e.g., in Pacific salmon fisheries). However, these management measures are also often used as a form of input control to limit fishing pressure. As a result, they may expose stocks (and species) that are available when the fishery is open to a higher fishing mortality than other stocks (and species) that are available during the protected season and area. It has been argued that selectively harvesting certain stocks has contributed to collapses of some commercially important stocks in European waters (25). Evidence from modeling and the history of erosion of population richness within the Northwest Atlantic cod and herring suggest that spatial and temporal management measures may simply result in a refocusing of fishing effort upon certain subpopulations, rather than the desired overall reduction in fishing pressure (27). Further, many Pacific salmon stocks (not species) have become extinct or severely depleted. Hilborn et al. (26) illustrate the importance of maintaining stock diversity for sockeye salmon, which is an amalgamation of several hundred discrete spawning populations. By maintaining stock diversity, the overall population has remained productive, despite major changes in climatic conditions affecting freshwater and marine environments during the last century. Stock diversity is one aspect of within-species biodiversity, which has received less attention in the biodiversity domain.

**Size Selection.** The desire to catch big fish is inherent in human nature, and the size of a fish can also affect its value. In addition, size selection is widely used in fisheries management, usually to limit exploitation before reproduction or to achieve optimal economic value. Size selection may alter diversity through reduction of intraspecies evenness and phenotypic variation, and evidence is mounting that size selection may trigger evolutionary change in a harvested population (28–31). Selectively catching large fish favors genotypes with slower growth, earlier age at maturity, smaller size, and other changes that can lower population productivity (32–36). Phenotypic changes in harvested systems have recently been shown to be much more rapid than changes reported in natural systems, as well as other human-driven perturbations in the wild, outpacing them by >300% and 50%, respectively (37, 38). Accordingly, harvested organisms show some of the most abrupt trait changes observed in wild populations. These changes, which include declines in size-related traits and shifts in life history traits, are most rapid in commercially exploited systems and thus may have profound conservation and economic implications. They suggest that the widespread potential for rapid and large effects on size- or life history–mediated ecological dynamics might imperil populations, industries, and ecosystems (31, 37). Although regulations on minimum size limits have often been imposed for good reasons, their negative impacts on genetic, population, and ecosystem diversity are being increasingly recognized (39, 40). Evidence also shows that size selection increases the variability of fish population abundance (22, 41, 42) and that fishery-induced evolution increases the stock rebuilding and recovery periods when large fish are selectively removed (43).

**Sex Selection.** Sex selection occurs when one sex is more valuable to society and hence commands a higher price, when females are protected to ensure reproductive output (30), and when one sex is larger than the other so is more vulnerable to fishing gear. Shellfish fisheries (e.g., for crabs and lobsters) often prohibit harvesting females in an attempt to maximize egg production, and such selection undoubtedly reduces intraspecies diversity. For example, reduced populations of large males can result in most of the mating by mature, but sublegal-sized, individuals that have fewer sperm (44). Hence, the long-term consequence of sex selection may be selection for individuals that never exceed the legal size limit (44). In addition to the significant sex-ratio imbalance caused by sex-selective fishing, it is estimated that only approximately half of all mature males for some crustaceans participate in spawning each year, owing to molting activity and spatial distribution (45). This means that the impact of male-only fishing is more severe on reproductive success than on simple sex ratio. Overfishing of one sex (male-only for crab and female-only for shrimp) has been considered one of the causes leading to the collapse of many stocks of crab and shrimp species in Alaska (46). A recent study has shown that the strength of sexual selection by fishing for smaller size is comparatively rapid when body size influences reproduction and variation in body size declines as fishing reduces the abundance of large fish (47).

**Season Selection.** Fisheries are often seasonal because of the annual migration or activity (e.g., spawning) of many marine fish. In addition to this natural seasonality, management plans commonly include temporal fishery closures as input controls to reduce fishing pressure, which may also impact biodiversity. Closed seasons disproportionately protect species, stocks, or individuals that migrate or are active during that period. They can also lead to more intensive fishing activity at other times, which in turn can result in greater impacts on species, stocks, or individuals that are genetically or behaviorally inclined to migrate or are active at other times (48). Quinn et al. (49) showed that salmon migration occurs earlier in response to high fishing pressure later in the season. Such directional shifts in behavior may affect sustainability, because progeny emerging too early may encounter unfavorable environmental conditions, as suggested by Cushing's match–mismatch theory (50).

**Space Selection.** Areas close to harbors and in shallow waters are more heavily impacted by humans (51). Evidence exists of sequential depletion of resources as distance from fishing ports increases (46). In addition to such spatial preference, spatial management has become a widely used tool to protect nursery grounds, or as a refuge for slow-growing or protected species. Although protection for particularly vulnerable species and stocks in closed areas may be beneficial, imposition of closures without other management measures can result in concentration of fishing effort in open areas. Consequently, species that are not particularly associated with the protected area can be subjected to higher impacts (27, 52, 53). Displaced effort due to area closures in a trawl fishery were predicted to increase the cumulative impacts on total benthic invertebrate production and lead to localized reductions in benthic biomass (52). The placement of closed areas is also crucial. A closed area placed in the feeding grounds of a stock can be effective in reducing fishing-induced evolution, although such an area placed in the spawning grounds can exacerbate the very evolutionary trends that this regulation aims to avoid (54).

In summary, the need to mitigate effects of unrestricted and unsustainable levels of fishing is the primary driver for the implementation of 6-S selection. However, belief in and hence the implementation of 6-S selection has been largely unquestioned. By contrast, there is growing evidence that this management paradigm has unintended (and often opposite) consequences when viewed at a system level. In fact, changing the current selective fishing philosophy could facilitate simultaneous achievement of both the ecosystem and fisheries management goals described by the Food and Agriculture Organization (1).

## The Concept of Balanced Exploitation

An overwhelming majority of research papers and management arrangements

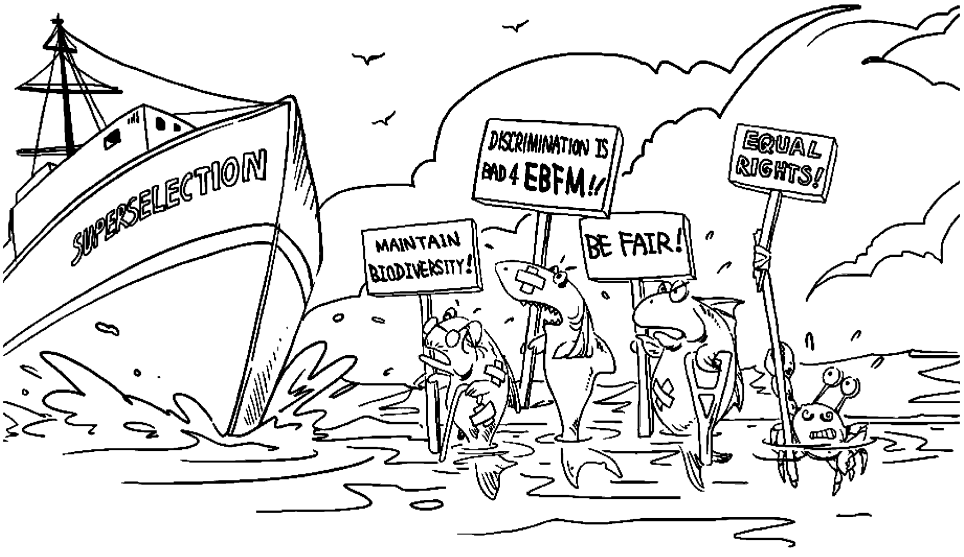

**Fig. 1.** Discriminated groups voice for balanced exploitation in EBFM.

encourage more selective fishing, whereas only a few publications advocate less selective fishing (16, 22, 55). Here we synthesize these currently unpopular ideas of less selective fishing and advance a concept of "balanced exploitation" for EBFM. All species and stocks can withstand some level of exploitation, and, as discussed above, there are ecological advantages in spreading fishing pressure, whether across genotypes, populations, or communities. The concept is similar in some ways to modern tax systems. Most governments impose income tax on their residents. Proportional or progressive tax systems attempt to impose a fair burden (relative to resources) on the rich and poor. Extrapolation of modern tax systems to fishery management would imply (*i*) harvesting all species, stocks, sizes, and sexes that can be used by humans (i.e., mainly the primary and secondary consumers in marine ecosystems), as long as their abundance and population growth rates are above certain thresholds; and (*ii*) more-productive species/stocks should sustain higher fishing mortality rates than less-productive ones. This approach deals with balance among species, stocks, sexes, and sizes in helping maintain sustainable fisheries, balanced ecosystems, and natural biodiversity, in contrast to conventional selective fishing strategies that strive for a clean catch of certain components of the ecosystem, often at quite high levels of exploitation (Fig. 1).

Within this concept, the ideas of threshold- and productivity-dependent exploitation are not new. In many fisheries, management policies restrain fishing mortality when a species' current population growth rate and/or abundance fall below a critical threshold. Such a threshold can be viewed as selectively protecting certain (vulnerable) species in contrast to the philosophy of selectively harvesting a few species. Application of such thresholds will maintain species richness by preventing overfishing of species that are particularly vulnerable to fishing impacts. Therefore, it is important to continue bycatch prevention measures for vulnerable species such as sea turtles and some sharks. Traditional fisheries management imposes exploitation rates on target populations based on their productivities. The balanced exploitation concept extends this productivity-dependent exploitation to all utilizable species and components. This change would require a substantial change in many fisheries, toward an expanded notion of what constitutes a fishery resource, reconsidering the perception of fisheries waste, and likely promoting cultural exchange and trade in utilization of the entire catch complex. From the ecosystem and fisheries point of view, this strategy avoids intensively removing a few species or particular components from an ecosystem and helps maintain interspecies diversity, intraspecies diversity, and sustainable fisheries (16, 22, 25, 55).

The balanced exploitation approach would help to alleviate fisheries crises arising from overfishing on a few selected target species. Regulations can be adjusted to reduce effort particularly on the target component of that complex that is overexploited, while maintaining or even increasing overall efficiency in utilization of fishery resources because utilization of the entire complex of harvested species is more balanced (56). It is expected that the global food demand will increase for at least another 40 years owing to continuing population and consumption growth (57). Increasing production limits, reducing waste, changing diets, and expanding aquaculture are suggested to meet the challenge of feeding 9 billion people (57). Balanced exploitation would increase fisheries production by using currently nontarget species while reducing unsustainably high pressure on current target species.

The balanced exploitation concept can be applied both as a high-level EBFM principle or goal and as a management strategy at an operational level. This principle means it is ideal to proportionally remove all utilizable species/components from an ecosystem except vulnerable ones. There is an urgent need to develop approaches based on theoretical and empirical comparative assessments of full ecosystem level impacts of selective and nonselective fishing strategies. Unavoidably, fishing will always be selective to some extent, and balanced exploitation on each ecological component will be difficult to achieve. Hence, at the operational level, a key step toward EBFM would be to critically rethink, and where appropriate revise, management regulations that adversely impact biodiversity and a sustainable fishery in the long term. For example, zero-bycatch goals, minimum fish size and mesh limits, and sex restriction policies should be critically reviewed for each fishery. A feasible approach may be to undertake much broader sustainability assessments for fishing effects (58) to ensure sustainability for all affected species. Such assessments evaluate each species' intrinsic capacity to sustain fishing impacts based on their life history traits, and identify vulnerable species depending on the temporal and spatial distribution and intensity of fishing activities. The simultaneous removal of a fraction of nontarget species, as long as it is sustainable, may mitigate ecosystem effects of fishing and increase net productivity of both the target and nontarget components (16, 22). Further, new fishing strategies should be developed to maintain biodiversity at both interspecific and intraspecific levels. For example, fishing gear designs and methods that impose a rate of fishing mortality that is proportional to productivity across a range of species should be encouraged instead of focusing on a small subset of target species and imposing increasingly high fishing mortality on single sex and large, scarce, old fish as they age.

Seeking less, rather than more, selectivity may also have economic benefits for the fishing industry. Most restrictions imposed to reduce bycatch result in some economic cost to the industry, usually through lower catch rates of the targeted species (59, 60). Incentive-based management systems (e.g., taxes or quotas) may be well placed to limit bycatch of vulnerable species (e.g., turtles, seabirds) without imposing undue restrictions on fishing activities (61). In addition to less selection, reducing fishing effort on target species will also result in lower levels of incidental fishing mortality. This is also in line with the view that ecosystem level exploitation rates will be lower than most single species exploitation rates (12).

Better utilization of the entire complex of marine ecosystems is embedded in the balanced exploitation concept. However, we acknowledge that balanced exploitation may create other issues at least temporarily in some parts of the world. For example, catch of low-value species will (at least in western countries) be seen as a problem and potentially viewed as waste of nature resource (1, 62). Research may be needed to increase the utilization of low-value species. Responsible models include many Asian and African countries where nearly all of the catch is used (63). Policies in many western countries have made it obligatory for bycatch to be landed (63, 64). The transfer of improved utilization technologies between fisheries and countries will be valuable in fostering food security and implementing balanced exploitation (57, 65). Even when discarding is unavoidable in the short term, we should realize that it is not a new or additional waste because utilizable and sustainable fish that are never caught and consumed by humans (including nontarget species that could be avoided through selective fishing) represent ongoing losses of fisheries resource to society anyway.

Research needs to support this approach include sustainability assessments of nontarget species, identification of vulnerable species, fishing gear design, study of better fishing strategies, and impact assessments that incorporate trophic feedback and potential evolutionary effects. Some of these needs have been widely discussed already in relation to calls for more selective fishing (1, 2, 5).

We acknowledge that a certain level of selection in fishing is inevitable and even appropriate, not least to avoid excessive exploitation rates on vulnerable species. We also believe it is now time to critically rethink traditional selective fishing approaches that might not protect ecosystems and fisheries as intended, but may in fact make them more vulnerable. A combination of reduced fishing effort (12), less selective fishing strategies, and better utilization of catch could help simultaneously achieve sustainable overall yields while maintaining ecosystem services and functions.

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