CONSERVATION

Reconsidering the Consequences of Selective Fisheries

Balanced fishing across a range of species, stocks, and sizes could mitigate adverse effects and address food security better than increased selectivity.

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Concern about the impact of fishing on ecosystems and fisheries production is increasing (*1*, *2*). Strategies to reduce these impacts while addressing the growing need for food security (*3*) include increasing selectivity (*1*, *2*): capturing species, sexes, and sizes in proportions that differ from their occurrence in the ecosystem. Increasing evidence suggests that more selective fishing neither maximizes production nor minimizes impacts (*4*–*7*). Balanced harvesting would more effectively mitigate adverse ecological effects of fishing while supporting sustainable fisheries. This strategy, which challenges present management paradigms, distributes a moderate mortality from fishing across the widest possible range of species, stocks, and sizes in an ecosystem, in proportion to their natural productivity (*8*), so that the relative size and species composition is maintained.

Selectivity: Rationale, Undesirable Effects

Fishers select species and sizes for various practical, economic, and regulatory reasons. The idea of increasing size-selectivity to increase yields is centuries old (*9*). The concept of growth overfishing (loss of yield when small fish are caught) has been a cornerstone of modern fisheries management since the 1950s (*10*). Avoiding juveniles has been justified to let fish reproduce at least once before they are harvested (*11*). Protecting rare and charismatic species has also gained currency (*12*). New guidelines from the United Nations Food and Agriculture Organization (FAO) reiterate the objective of "minimizing the capture and mortality of species and sizes which are not going to be used," i.e., by-catch (*13*). Fisheries worldwide have used species and size limits (*9*, *14*), gear technology (*5*, *15*), and spatial and temporal fishing restrictions (*16*) to reduce fishing impacts while pursuing human benefits.

But selective removals will inevitably alter the composition of a population or community and, consequently, ecosystem structure and biodiversity. Old individuals contribute the most to reproduction (*17*). Even moderate fishing reduces the proportion of large and old fish in a population. Selectively fishing large individuals amplifies this effect, and although it does not provide the expected yield benefits (*9*), it results in ecological and evolutionary side effects. Removal of older age classes can increase fluctuations in population abundance (*18*), which, in turn, increase the risks associated with low abundance. Increased and selective fishing has been predicted to drive stocks toward earlier maturation and smaller adult body size (*19*). Such changes appear common (*20*), although their environmental and genetic causes are not fully disentangled (*21*).

> *Balanced harvesting … distributes a moderate mortality from fishing across the widest possible range of species, stocks, and sizes in an ecosystem.*

Community effects of heavy, selective exploitation include alteration of trophic structure on the Eastern Scotian Shelf (*6*), and a shift from large- to smaller-sized species and individuals in the North Sea (*22*) (fig. S1). By contrast, in several African small-scale inland fisheries, the fish size spectrum (*23*) has been maintained under intense and diverse fishing activities that cause high mortality with low selectivity (*5*, *24*) (fig. S1).

Results from models suggest that moderating fishing mortality across a wide range of species and sizes maximizes overall catch summed across species while better conserving biodiversity. Multispecies fishery models show that increased mesh sizes may reduce total yield, owing to increased predation by large fish (*25*), and that targeting a limited range of species or sizes will not maximize diversity at most fishing mortalities (*26*). In size-based models, depletion of particular sizes by fishing affects smaller-size groups because their predation mortality is reduced and impinges on larger-size groups by both reduced food for predators of the harvested sizes and faster growth rates of the survivors of the selective fishing. This causes destabilizing fluctuations in biomass that are wider when the size range fished is narrower and/or the sizes fished are large (*27*). When models allow for some diversity in properties other than size within size classes, fluctuations persist but are dampened (*28*).

Synthesizing across ecosystem models from 30 systems [see supporting online material (SOM) for details] suggests that the biodiversity benefits from selective fishing occur only at fishing mortalities so low that yield is not economically sustainable (see the graph). With fishing spread over more groups and sizes, yields are higher and impacts of fishing—such as population extirpations (local extinctions) and biomass depletion—are lower across a broad range of fishing mortalities.

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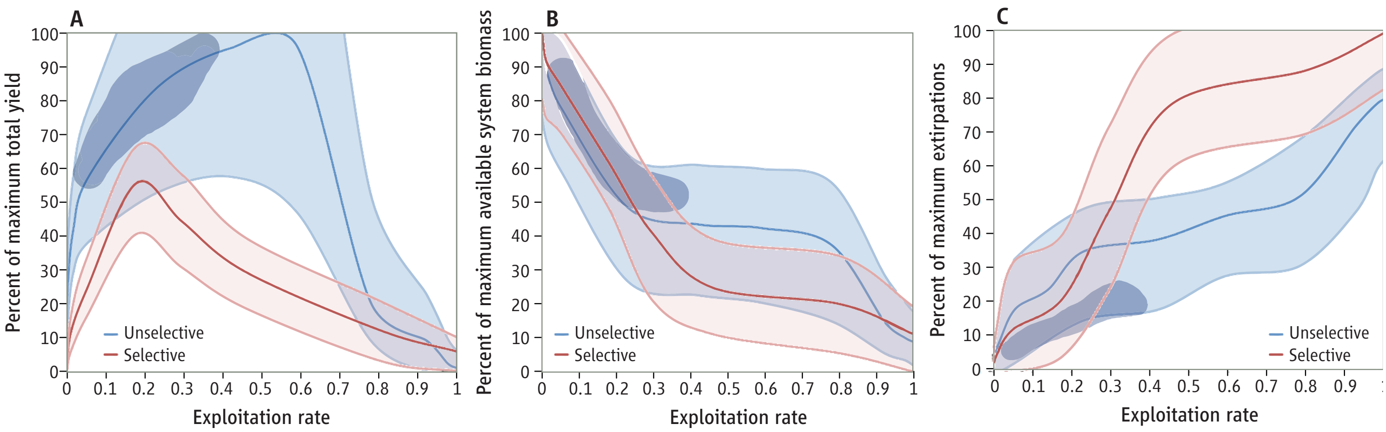

Effects of conventionally selective (red), unselective (blue), and balanced (dark blue) fishing. Unselective fishing harvests all exploitable nonmicrofauna and nonlarval ecosystem components. Balanced fishing mortality rates are set in proportion to productivity per biomass for each group. (**Left**) Results for total catch weight (as a percentage of the maximum total yield for a system across all fishing scenarios), (**middle**) total available biomass (i.e., biomass that could be harvested), and (**right**) extirpations (number of groups that have dropped below 10% of their unfished levels). All values are plotted against the maximum system level exploitation rate (i.e., roughly total catch as a proportion of total available biomass). For each fishing type (conventionally selective or unselective), the solid line is the average across 36 ecosystem models, and the lower and upper bounds of the lightly shaded areas represent the 5th and 95th percentiles across models. The darker blue shaded areas encompass >90% of the balanced harvest scenarios across the ecosystems. See SOM for details; the selective fishing results were part of supplementary fig. S1 in (*2*).

Toward Balanced Harvesting

The conventional "increased selectivity" paradigm may be inconsistent with objectives of an approach that considers all ecosystem consequences while managing fisheries. Balanced harvest is selective, but it broadens the selectivity perspective from scales of fishing operations and stocks to the integrated scale of ecosystem productivity and impacts.

Conventionally selective removal of parts of the ecosystem leads to unintended consequences that are inconsistent with a range of international conventions and agreements, including the international commitment to rebuild world fish stocks to their maximum sustainable yield (MSY) (*29*, *30*). It is increasingly recognized that all stocks within an ecosystem cannot be rebuilt to biomasses consistent with their single-species MSY levels (*31*). If the focus is on how much to fish as calculated from reducing fishing mortality (*1*, *2*), MSY's dependence on what type of fishing is done—size-selectivity within stocks and species-selectivity at the community level (*32*)—is overlooked. Balanced harvesting requires adjusting selectivity regulations to balance the impact of all fisheries in an area with the relative productivities of the species and sizes of fish in the ecosystem; MSYs are subject to that constraint.

Regulations in many jurisdictions promote selectivity as an intended outcome, e.g., by using mesh-size limits. Our results suggest that such regulations often will be inconsistent with goals to maintain biodiversity as well as fish yield. Implementing balanced harvesting requires coordinated management across multiple fisheries with consideration of ecosystem structure, consequences of current fishing selectivity, and implications for future yields. This involves quantifying patterns of fishing activities and ecological consequences aggregated at the fish-community and ecosystem levels.

We propose that fisheries management should address community properties such as the size-spectrum slope, for which acceptable levels would be agreed (*33*, *34*). Ecosystem modeling could help in determining appropriate patterns of fishing mortality and selectivity to conserve these properties, and constraints on removals (including discards), not just landings. Perhaps the greatest changes required for a balanced harvesting approach concern by-catch and markets. As each ecosystem component is to be caught in appropriate amounts, by-catch ceases to be an operational nuisance to be minimized and becomes part of the management strategy. Markets and the processing sector will need incentives to accommodate a wider range of catch components, including many not currently utilized in Western countries but commonly used in multispecies, multigear fisheries (*5*, *35*) in the Mediterranean, Asia, and the Southern Hemisphere: for example, (i) enhancing industrial processing for animal feed or human consumption (*36*), (ii) status change from by-catch to target (*14*), and (iii) consuming less-utilized fish species (*37*).

Issues regarding the potential benefits and implementation of balanced harvesting remain. However, consideration of food security and minimizing ecosystem impacts suggest that the time has come to take action.

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PUBLIC HEALTH AND BIOSECURITY

The Limits of Government Regulation of Science

A transparent institutional review process will balance scientific freedom and national security better than publication restrictions.

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Last summer, two research teams funded by the National Institutes of Health genetically modified H5N1 avian influenza viruses, making them capable of efficient respiratory transmission between ferrets. Ferrets are thought to be a good animal model for influenza in humans. A small number of genetic changes might be able to convert the presently zoonotic H5N1 virus into a pathogen with dangerous pandemic potential—transmissible from human-to-human, with a >50% case-fatality rate. The National Science Advisory Board for Biosecurity (NSABB), which advises the U.S. Department of Health and Human Services (HHS), recommended that two journals, *Science* and *Nature*, redact key information before publication. The NSABB and HHS expressed concerns that published details about the papers' methodology and results could become a blueprint for bioterrorism (*1*).

The U.S. government's request not to publish key scientific findings sparked considerable controversy. To many researchers, knowledge about what mutations enable respiratory transmission is essential to surveillance of and early action against variants of H5N1. They worry that government intrusion into scientific innovation would discourage vital research. However, security advocates believe the greater risk is that the mutated virus could escape or that knowledge about these mutations could get into the wrong hands. They suggest that research of this kind should not be funded or undertaken in the first place. Where, as here, the research has already been conducted, they urge scientific journals not to publish any sensitive methods or results (*1*).

The HHS request reveals a troubled relationship between security and science. This is not the first time a government has requested that a journal not publish information. In 1979, the U.S. Department of Energy secured an injunction against the magazine *The Progressive* to prevent the publication of an article about building a hydrogen bomb, even though the information was in the public domain; the injunction was later vacated when the article was published elsewhere (*2*). In 2005, the *Proceedings of the National Academy of Sciences* refused to comply with an HHS request to decline publishing a mathematical model of botulism in the milk supply (*3*). The H5N1 case, however, is the first time government has sought to redact information after an institutionalized HHS review process.

The court ruled that federally funded scientific research, especially at universities, should be free from prior restraint—calling into question the validity of CUI conditions on research grants.

Constitutional Limits on Government Restrictions of Scientific Publications

The First Amendment to the U.S. Constitution affords considerable protection to political, artistic, and scientific expression, that could trigger "strict scrutiny" by the Supreme Court (*4*). The court is most vigorous in reviewing government restraints on speech in advance of publication, which it calls "prior restraints." Prior restraints are uniquely threatening to First Amendment values because they prevent ideas from ever being heard (*5*).

Had the government compelled the H5N1 researchers to cease research or the journals to withhold publication—whether through the force of law or by creating adverse consequences such as loss of funding—it could have violated the First Amendment. Even informal systems of restraint can be unconstitutional, such as a government threat to prosecute publishers (5). In this case, however, HHS' request, by its own terms, was nonbinding, and the journals had discre-

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