Encyclopedia of Earth

Marine biodiversity and food security

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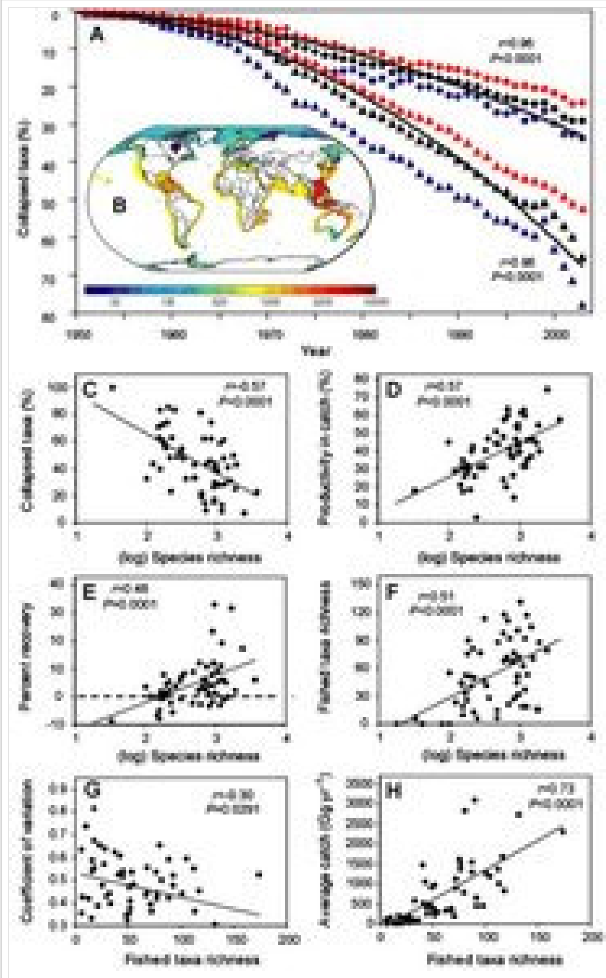
Introduction

Harvesting of wild fish and shellfish from the oceans provides an important source of protein to earth's population, particularly in the developing world, and is a major contributor to the world economy. In the USA alone, fishing supports an industry worth nearly $50 billion annually. Although fishing commenced very early in human history, it was during the 20th century that its reach and impact spread around the globe and into deep waters, first with the advent of motorized vessels near the turn of the century, and later as a result of widespread availability of cheap oil, refrigeration, and increasingly effective technology. These developments made fishing an intensive global industry, particularly after Word War II. Modern fisheries, including both landings and by-catch, currently consume 24-35% of global marine primary production in the continental shelf and major upwelling areas, corresponding closely to recent estimates that humans now appropriate roughly one quarter of the land's potential net primary production as well. Humans are thus the dominant marine predator on earth. And our appetite appears to be near the limit of what the oceans will bear. As of 2005, the United Nations' Fisheries and Agricultural Organization (FAO) reported that 52% of world fisheries stocks are currently "fully exploited", meaning that they are being harvested at rates estimated to be near their maximum sustainable limit, 24% are overexploited or depleted, meaning that they are being harvested at rates not sustainable in the long term, and 1% are considered to be recovering from depletion.

This intense and sustained fishing pressure has had multifarious impacts, both direct and indirect, on the environment and biodiversity of the oceans. Direct impacts include, for example, damage to the seabed from trawling or to coral reefs from dynamite fishing. Indirect impacts arise as the reduced abundance of harvested species ripples through the food web. For example, the blooms of jellyfish that have increased rapidly worldwide in the last decade are believed to result in part from “fishing down the food web” – as fisheries depleted large predators they turned to smaller, plankton-feeding fishes such as anchovy and sprat, whose removal allowed zooplankton populations to increase, providing abundant food for jellyfish. Jellyfish have thus replaced fishes as the dominant planktivores in several areas, and there is some concern that these community shifts may not be easily reversible, since the jellyfish also eat the eggs of their fish competitors.



Trends in marine fishery catches as a function of fish diversity. (A) Trajectories of fish and invertebrate collapses (i.e., falling below 10% of maximum historical harvest) over the last 50 yr (♦=collapses by year, ▲=cumulative collapses). Data are shown for all (black), species-poor (<500 species, blue) and species-rich (>500 species, red) Large Marine Ecosystems (LMEs). Regression lines are best fit power models corrected for temporal autocorrelation. (B) Map of all 64 LMEs, color-coded by total fish species richness. (C) Proportion of fish and invertebrate taxa that had collapsed, (D) average productivity of non-collapsed taxa (in % of maximum catch), and (E) average recovery of catches (in % of maximum catch) 15 yr after a collapse in relation to LME fish species richness. (F) Number of fished taxa as a function of total species richness. (G) Coefficient of variation in total catch, and (H) total catch per year as a function of the number of fished taxa per LME. (Source: Worm et al. 2006

In the last few decades, human impacts on the oceans have rapidly become more visible and pervasive. Many scientists believe that earth is now in the midst of a major extinction of species and a worldwide reorganization of ecological communities driven by human transformation of the global environment. The oceans were long considered immune from these impacts, but it is now clear that many marine species also are being severely depleted. Although few marine species have gone extinct globally, many have been lost from local communities as their numbers have dwindled and they have been restricted to small refuge areas. This loss of biodiversity from the oceans has potentially profound consequences because, unlike terrestrial agriculture, which involves intensive management to maximize production, marine fisheries harvest the produce of wild marine ecosystems. Thus, seafood harvests are much more intimately dependent than terrestrial agriculture is on natural infrastructure in the form of biodiversity—the variety of interacting wild animals, plants, and microbes—and the habitats that support them. This dependence of fisheries on natural ecosystems raises an important question: How might this ongoing loss of biodiversity affect the supply of seafood to the human population and economy?

The functional significance of marine biodiversity

Insights from experiments

The consequences of changes in diversity and composition of biological communities for ecosystem functioning have been an active topic of research in recent years. There is particularly strong interest in how such changes influence the services that ecosystems provide to humans, such as food production (including fisheries but also pollination and agricultural pest control), water and air purification, waste disposal, coastal erosion control, etc. Most research on links between biodiversity and ecosystem functioning has involved small-scale, controlled experiments. A growing body of such research reveals that changing biodiversity can influence several properties of marine food webs and ecosystems, including nutrient use and cycling, productivity, transfer of energy and materials between trophic levels, and the stability of these processes. First, experiments show that in communities with multiple prey species, the total biomass of prey is often more resistant to control by predators than where only one or a few prey species are present. In other words, prey diversity provides some resistance to top-down control. One reason, apparently, is that diverse biological communities contain species with a range of lifestyles and characteristics, so they are more likely by chance alone to contain at least one prey species that is resistant to predation. Second, because co-occurring species tend to differ in how they use resources, diverse communities of marine organisms tend to use resources more completely than do communities of only a few species. That is, higher diversity can enhance efficiency of the community's total production and tends to result in higher total biomass in a given area. Third, diverse communities of prey organisms (including algae) generally support better growth and condition of predators (or herbivores) than do single prey species, evidently because the diverse prey provide a more balanced diet. This has been demonstrated experimentally for marine protozoans, crustaceans, and sea urchins. Finally, experiments with plants and sessile invertebrates show that more diverse communities tend to show less variation in biomass through time, and to resist disturbance better and recover from disturbance faster, than do communities with few species. That is, diverse communities tend to be more stable in the face of changing environments.

Importance of biodiversity for fisheries: the evidence

The experimental evidence, mostly based on small-scale studies, thus suggests several important links between biodiversity and marine ecological processes. These generalizations have potential implications for fisheries, and consequently for human well-being. But can the conclusions from these studies really be extrapolated to predict effects of declining biodiversity at the large spatial and temporal scales in which fisheries operate in real marine ecosystems?

To answer this question, it's worth first specifying what is meant by biodiversity loss. It's easy to understand that extinction of a fish species would be detrimental to the fisheries that target it directly. But complex interactions among species can also produce important rippling influences of loss of a species on the structure and dynamics of ecosystems. For example, the blue crab (*Callinectes sapidus*) is one of the largest fisheries in the Chesapeake Bay, USA, with a value of almost 19 $M in Virginia alone in 2004. Blue crabs have declined in abundance in recent decades, partly as a direct result of fishing, but also as an indirect consequence of loss of seagrasses that provide nursery habitat for young crabs. Similarly, when wasting disease decimated eelgrass (*Zostera marina*) throughout the North Atlantic in the 1930s, the Maryland and Virginia fisheries for bay scallops, which depend on eelgrass, crashed and never rebounded. These examples show how loss of a major habitat-forming species, eelgrass, can have important indirect consequences for other species.

Bluefin tuna have been severely overfished and some scientists believe they are in danger of extinction. (Source: NOAA)

The commonness of these indirect,and often unpredictable, interactions among species raises the broader question of whether species richness per se—the number of species rather than the presence of particular species—has predictable effects on how natural ecosystems work. A recent study involving collaboration of 14 marine ecologists, fishery researchers, and resource economists sought to answer this question, focusing on how the variety of ocean life might benefit human society. This effort synthesized data from a wide range of sources from the laboratory experiments discussed above to global surveys of fisheries data. At the global scale, these authors analyzed relationships between fish species richness and fishery production across the world's 64 Large Marine Ecosystems, which vary naturally in diversity. Surprisingly, the results were generally consistent across scales, from short-term laboratory experiments to patterns in fishery dynamics on a global scale. The global survey showed that ecosystems with naturally low diversity had lower fishery productivity, more frequent "collapses" (operationally defined as strong reductions in fishery yield), and lower tendency to recover after overfishing than naturally species-rich systems. Given that any such large-scale comparison inherently involves various confounding factors, it is all the more striking that the correlations with diversity found in the global fishery data match closely the expectations from theory and the results of small-scale experiments.

Importance of biodiversity for fisheries: mechanisms

What mechanisms might explain these trends? One likely explanation for the greater resilience of more diverse ecosystems is that fishers can switch more readily among target species when there are many species available, potentially providing depleted species a chance to recover before their populations are irreparably harmed. This mechanism is consistent with theory, small-scale experiments, and with the finding of lower variation among years in total catch in ecosystems with higher fish diversity. It is also consistent with the finding of apparent compensatory change in exploited fish communities. For example, in the tropical Atlantic, longline fisheries for billfish show a pattern of sequential peaks in catch of different species, with decline of prized blue marlin in the 1960s accompanied by a rise in catch of sailfish, which then declined in turn as swordfish catches increased through the late 1970s and 1980s. The result was that total billfish catch remained relatively stable through time despite boom and bust patterns in the catch of individual species. A similar pattern has been seen on Georges Bank, where the decline of cod through the 1960s was accompanied by a steep rise in flatfishes. It has also been suggested that the booming Maine lobster catches of recent years may reflect their release from predation by the now collapsed stocks of predatory cod.

Seafood for sale at a fish market in the Malaysian city of Kota Kinabalu. (Source: Photo by Emmett Duffy)

These findings suggest that biodiversity can provide a form of security with an analog in financial markets: a diverse portfolio of fish stocks, like a portfolio of business stocks, can buffer an investment against fluctuations in the market (or the environment) that cause major declines in individual stocks, thus preserving society’s options in the face of change. This stabilizing effect of a biodiverse portfolio is likely to be especially important as environmental change accelerates with global warming and other human impacts.

For the industries that harvest seafood, and the human societies that are obliged to manage these public resources, the implication of these results is one that has not yet been widely integrated into fishery management, namely that productive fisheries that are sustainable over the long term depend on a normally functioning ocean ecosystem. This in turn depends on a variety of less conspicuous, easily ignored species of microscopic plankton, small invertebrates, coastal wetland plants, and so on. Growing evidence from a variety of sources indicates that loss or reduction of such species often has consequences that ripple out through the food web, degrading the ocean’s capacity to provide not only fish harvests, but other services to humanity such as coastal erosion control and water purification. If such interactions are indeed general—and the concordance of theory, experiments, and observed trends in global fishery catches suggest that they are—they imply that continuing erosion of ocean biodiversity has real potential to compromise food security, particularly for the developing nations and small island states whose populations and economies depend heavily on wild fish harvests. In summary, loss of ocean biodiversity is more than just an esthetic issue, it portends significant consequences for human health, economic and food security.

Can we preserve both ocean biodiversity and fisheries?

Threats to the ocean are multifaceted, and the solutions need to be as well. Effective ocean conservation and management involve three R’s: *Reserve* unspoiled habitats where possible, *Restore* degraded ones, and *Reconcile* the several, often competing, demands of human society with the need for long-term sustainability of the natural infrastructure that feeds those demands. One promising approach that begins to address all three of these goals is ocean zoning, that is, designation of certain areas for particular uses and others that are partly or fully protected. Such zoning has been used routinely on land for many years. The growing network of limited-access or no-take marine reserves helps address both the reservation of relatively untouched habitats and the restoration of degraded ones. Marine protected areas (MPAs) allow fishes and other organisms to reach the high abundances and large body sizes necessary to maintain stable reproductive populations, and can help maintain both biodiversity and productive fisheries. Zoning for other uses such as recreation, fishing, and energy generation can, if done properly, reconcile the various needs of human society with effective preservation of ecosystem structure and services. Obviously, the long-term effectiveness of such zoning will also depend on continuing efforts to reduce inputs to the oceans of toxic materials and the nutrients that produce dead zones, to develop adjacent coastal watersheds responsibly, and to minimize human-induced climate change.

A second general approach to making fisheries more sustainable involves ecosystem-based management (EBM). Historically, governance and management of marine ecosystems has been fragmented among largely isolated agencies and regulatory bodies. Analysis and decision-making focus narrowly on specific issues, such as management of particular fish stocks, coastal development, water quality, and human health. Yet it is well known that there are complex interactions and feedbacks among species, environmental parameters, and human impacts. EBM thus aims to provide an integrated, place-based approach to simultaneous management of interrelated human activities and ecosystem processes. Ecosystem-based management has been mandated by, for example, the Great Barrier Reef Marine Park Act of 1981 in Australia, the Magnuson-Stevens Fishery Conservation and Management Act (1996, reauthorized 2006) in the USA, and the International Convention on the Conservation of Antarctic Marine Living Resources. Due to the complexity of the tasks, it is no surprise that implementation of EBM remains an evolving science.

Finally, aquaculture is frequently suggested as a solution to the environmental impacts of exploiting wild fish stocks. But the answer is not simple. Farming carnivorous fishes like salmon can cause as much or more environmental harm than wild capture fisheries because carnivores demand large quantities of food, which typically comes from forage fish harvested from the ocean, and also because of their prodigious waste output. If aquaculture is to be part of an environmentally (and economically) sustainable long-term solution, rather than part of the problem, it must employ animals low on the food chain such as catfish and tilapia, avoid transmitting diseases and genetic defects to wild fish, and produce minimal waste and habitat destruction. Achieving these goals requires effective management and policy.

A major challenge for conservation, which is even more acute in the oceans than on land, is that the greatest threats to the environment now are global in scope. Foremost among these, in addition to fishing, are climate change and ocean acidification resulting from fossil fuel combustion and associated carbon emissions. Solutions to these global problems will require new, more effective international governance structures and agreements, and prompt action.

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