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The Future for Fisheries

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Formal analyses of long-term global marine fisheries prospects have yet to be performed, because fisheries research focuses on local, species-specific management issues. Extrapolation of present trends implies expansion of bottom fisheries into deeper waters, serious impact on biodiversity, and declining global catches, the last possibly aggravated by fuel cost increases. Examination of four scenarios, covering various societal development choices, suggests that the negative trends now besetting fisheries can be turned around, and their supporting ecosystems rebuilt, at least partly.

Fisheries are commonly perceived as local affairs requiring, in terms of scientific inputs, annual reassessments of species-specific catch quota. Most fisheries scientists are employed by regulatory agencies to generate these quota, which ideally should make fisheries sustainable and profitable, contributors to employment and, through international trade, to global food security.

This perception of fisheries as local and species-specific, managed to directly benefit the fishers themselves, is conducive neither to global predictions nor the collaborative development of long-term scenarios. Indeed, recent accounts of this type, except those of the United Nations Food and Agriculture Organization (FAO) (*1*), tend to be self-conscious and layered in irony (*2*–*5*), perhaps an appropriate response to 19th-century notions of inexhaustibility.

The past decade established that fisheries must be viewed as components of a global enterprise, on its way to undermine its supporting ecosystems (*6*–*10*).

These developments occur against a backdrop of fishing industry lobbyists arguing that governments drop troublesome regulations and economists assuming that free markets generate inexhaustibility. The aquaculture sector offers to feed the world with farmed fish, while building more coastal feedlots wherein carnivores such as salmon and tuna are fed with other fish (*11*), the aquatic equivalent of robbing Peter to pay Paul.

The time has come to look at the future of fisheries through (i) identification and extrapolation of fundamental trends and (ii) development and exploration (with or without computer simulation) of possible futures.

The fisheries research community relied, for broad-based analyses, on a data set now shown to be severely biased (*10*). First-order correction suggests that rather than increasing, as previously reported, global fisheries landings are declining by about 500,000 metric tons per year from a peak of 80 to 85 million tons in the late 1980s. Because overfishing and habitat degradation are likely to continue, extrapolation may be considered (see below). This correction, however, does not consider discarded "by-catch" (about 30% of global landings), only one component of the illegal, unreported, or unregulated (IUU) catches that recently became part of the international fisheries research agenda (*12*, *13*).

The geographic and depth expansion of fisheries is easier to extrapolate (Fig. 1). Over the past 50 years, fisheries targeting benthic and bentho-pelagic organisms have covered the shelves surrounding continents and islands down to 200 m, with increasing inroads below 1000 m, whereas fisheries targeting oceanic tuna, billfishes, and their relatives covered the world ocean by the early 1980s (*9*).

Extrapolating the bottom fisheries trends to 2050 is straightforward (Fig. 1). With satellite positioning and seafloor-imaging systems, we will deplete deep slopes, canyons, seamounts,

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and deep-ocean ridges of local accumulations of judiciously renamed bottom fishes, e.g., orange roughy (previously "slimeheads"), Chilean seabass (usually IUU-caught Patagonian toothfish), and hagfish (caught for their "eelskins," and here predicted to become a delicacy in trendy restaurants, freshly knotted and sautéed in their own slime), the abyssal tripodfishes being the only group that seems safe so far. Figure 1 also shows the radical trend change required to turn 20% of the shallowest 100 m of the world ocean into marine reserves by 2020, i.e., returning to the 1970s state.

Traditional explanations of overfishing emphasize the open-access nature of the fisheries "commons." However, overcapitalized fisheries can continue to operate after they have depleted their resource base only through government subsidies (*12*, *14*). Moreover, industrial fisheries depend upon cheap, seemingly superabundant fossil fuels (*15*), as does agriculture. Thus, we shall here venture a prediction counter to the trends in Fig. 1, based in part on the global oil production trend in Fig. 2A: If fuel energy becomes as scarce and expensive in the next decades as suggested by a number of independent geologists (*16*), then we should expect the most energy-intensive among industrial fisheries to fold. This would mainly impact deep-sea bottom trawling, which drives the trends in Fig. 1.

One effect may be to increase human consumption of small pelagics (mackerels, herrings, sardines, or anchovies such as the Peruvian anchoveta), now mostly turned into fish meal for agriculture (to grow chickens and pigs, and for use as fertilizer) and aquaculture.

However, predictions are better embedded into scenarios—sets of coherent, plausible stories designed to address complex questions about an uncertain future (*17*). Scenario analysis is especially important for the fisheries sector, which, although a major provider of food and jobs in many poorer countries, is small relative to the economy of richer countries and is thus "downstream" from most policy decisions.

Pending the detailed analysis of coastal and marine scenarios by the Millennium Ecosystem Assessment (*18*, *19*), we use the four scenarios developed by the United Nations Environment Programme (*20*) to investigate the future of marine fisheries. For each scenario, we also summarize results of regional simulation models explicitly accounting for interspecies feeding interactions, within a range of ecosystem types and fisheries (*21*, *22*).

1) Markets First, where market considerations shape environmental policy. This may imply the gradual elimination of the subsidies fuelling overfishing (*13*). Putting markets first may also imply the suppression of IUU fishing (including flags of convenience), which distorts economic rationality as insider trading or fraudulent accounting does. Markets First, by overcoming subsidies, could also lead to the decommissioning of fuel-guzzling distant-water fleets (especially large trawlers), and perhaps lead to a resurgence of small-scale fleets deploying energy-efficient fixed gears. This scenario allows for spontaneous emergence of quasi-marine reserves (i.e., areas not economically fishable, particularly offshore) and thus may reduce the impact on biodiversity. However, high-priced bluefin tuna, groupers, and other taxa (including invertebrates) would remain under pressure.

When modeled, this scenario corresponds to maximizing long-term fisheries "rent" (ex-vessel values of catch minus fishing costs). This usually leads to combinations of fleets exerting about half the present levels of effort, targeting profitable, mostly small, resilient invertebrates and keeping their predators (large fishes) depressed. Shrimp trawlers presently operate in this way, with tremendous ecological impacts on bottom habitats.

2) Security First, where conflicts and inequality lead to strong socioeconomic boundaries between rich and poor. This scenario, although implying some suppression of IUU fishing, would continue "fishing down marine food webs" (*6*), including in the High Arctic, and subsidization of rich countries' fleets to their logical ends, including the collapse of traditional fish stocks. This implies development of alternative fisheries targeting jellyfish and other zooplankton (particularly krill) for direct human consumption and as feed for farmed fish. This scenario, generally accentuating present ("south to north") trading patterns, would largely elimi-

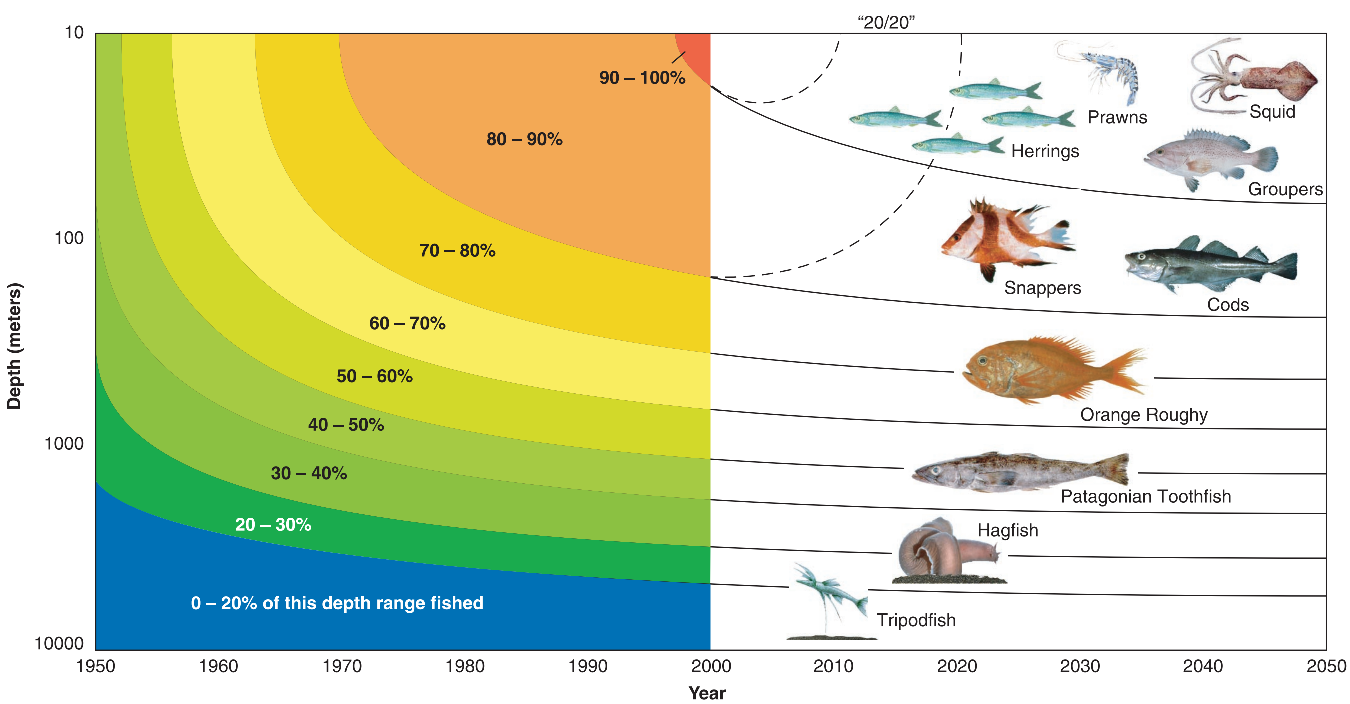

Fig. 1. Fraction of the sea bottom and adjacent waters contributing to the world fisheries from 1950 to 2000 (*30*) and projected to 2050 by depth (logarithmic scale). Note the strong reversal of trends required for 20% of the waters down to 100-m depth to be protected from fishing by 2020.

nate fish from the markets of countries still "developing" in 2050.

This scenario would also increase exports of polluting technologies to poorer countries, notably coastal aquaculture and/or fertilization of the open sea. This would have negative impacts on the remaining marine fisheries in the host countries, through harmful algal blooms, diseases, and invasive species.

We simulated this scenario through fleet configurations maximizing long-term gross returns to fisheries (i.e., ex-vessel value of landings plus subsidies, without accounting for fishing costs). The results are increasing fishing effort, stagnating or declining catches, and loss of ecosystem components, i.e., a large impact on biodiversity.

3) Policy First, where a range of actions is undertaken by governments to balance social equity and environmental concerns. This is illustrated by the recent Pew Oceans Commission Report (*23*), which for the United States, proposes a new Department of the Ocean and regional Ecosystem Councils, and a reform of the Fisheries Management Councils, now run by self-interested parties (*24*).

Similar regulatory reforms, coordinated between countries, combined with marine reserve networks, massive reduction of fishing effort, especially gears that destroy bottom habitat and generate large "by-catch" (*25*), and abatement of coastal pollution, may bring fisheries back from the brink and reduce the danger of extinction for many species.

This scenario corresponds to simulations where rent is maximized subject to biodiversity constraints. We found no general pattern for the fleet configurations favored under Policy First, because the conceivable policies involve ethical and esthetic values external to the fisheries sector (e.g., shutting down profitable fisheries that kill sea turtles or marine mammals).

4) Sustainability First requires a value system change, favoring environmental sustainability. This scenario, which implies governments' ratification of and adherence to international fisheries management agreements and bottom-up governance of local resources, would involve creating networks of marine reserves and careful monitoring and rebuilding a number of major stocks (*26*). This is because high biomasses provide the best safeguard against overestimates of catch quotas and environmental change (*11*), the latter not covered here but likely to impact future fisheries.

We simulate this scenario by identifying the fishing fleet structure that maximizes the biomass of long-lived organisms in the ecosystem. This requires strong decreases in fishing effort, typically to 20 to 30% of current levels, and a redistribution of remaining effort across trophic levels, from large top predators to small prey species.

These scenarios describe what might happen, not what will come to pass. Still, they can be used to consider what we want for our future. We have noted, however, that many of the fisheries we investigated, e.g., in the North Atlantic (*27*) or the Gulf of Thailand (*28*), presently optimize nothing of benefit to society: not rent [taxable through auctions (*29*)], and not even gross catches (and hence long-term food and employment security). It is doubtful that they will be around in 2050.

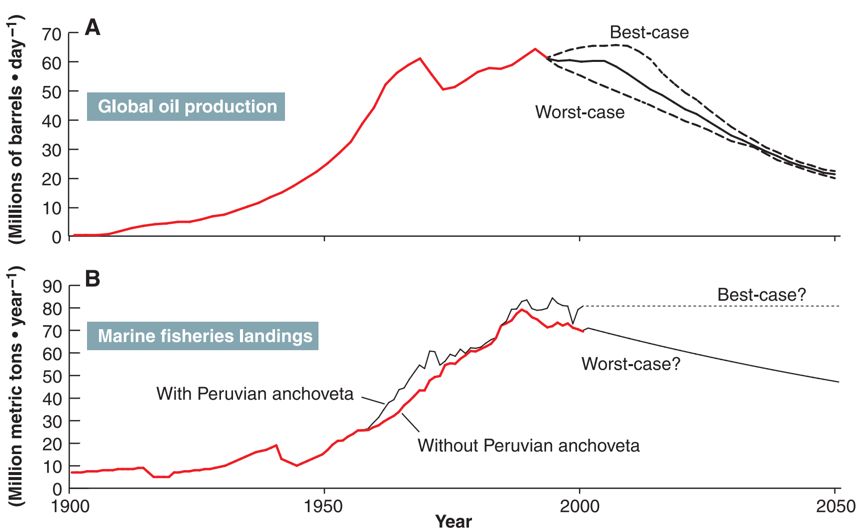

Fig. 2. Recent historical patterns and near-future predictions of global oil production and fish catches (1900 to 2050). (**A**) Various authors currently predict global oil production to decline after ~2010 (*16*), based on M. King Hubbert's model of reservoir depletion, with worst, medium, and best cases based on different assumptions about discoveries of new oilfields. (**B**) Global marine fisheries landings began to decrease in the late 1980s (*10*). The smoothly declining trend extrapolates this to 2050 and also reflects the potential effect of future, exceedingly high fuel prices. The flat line, i.e., sustaining present landings, would result from implementing proactive components of the Market First and Policy First scenarios.

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Web Resources

www.sciencemag.org/cgi/content/full/302/5649/1359/DC1