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World Fisheries

The Next 50 Years

DANIEL PAULY, JACKIE ALDER, ELENA BENNETT, VILLY CHRISTENSEN, PETER TYEDMERS, and REG WATSON

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 quotas. Most fisheries scientists are employed by

regulatory agencies to generate these quotas—which ideally should make fisheries sustainable and profitable, contributors to employment and, through international trade, contributors to global food security.

This perception of fisheries as local and species-specific, managed to directly benefit the

KEY TERM

Bottom fisheries: These are generally for groundfish species such as rockfish, cod, and sole, which are caught by bottom trawling, the fishing practice of dragging large nets weighted with chains, rollers, or rock-hopper gear across the seafloor. Trawling is the fishing practice most destructive of marine habitats.

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SCIENCE IN THE NEWS

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SCIENCE IN IRAN: THE STURGEON'S LAST STAND

Richard Stone

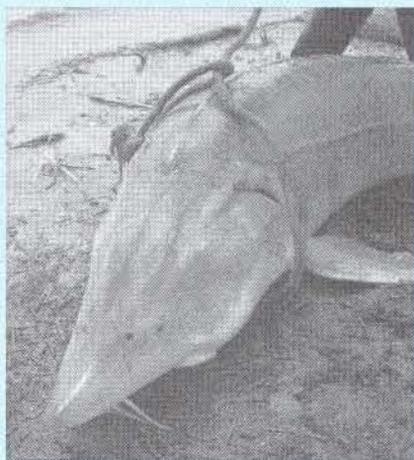
RASHT, IRAN—In a cavernous hall packed with naval-gray steel tanks, a precious commodity is being enriched and multiplied. No, this is not a hitherto undeclared uranium facility in Iran's nuclear program: It's a breeding facility for Caspian sturgeons. Each tank is filled with fish of various ages, from fingerlings, a few centimeters long with crocodilian snouts, to meter-long juveniles. Here at the International Sturgeon Research Institute (ISRI) in the northern town of Rasht, scientists are refining techniques for rearing fingerlings that may give the ancient but threatened species a better shot at surviving in the open sea. "If something happened in the Caspian and a wild population was lost, we could reconstitute it," says ISRI director Mohammad Pourkazemi.

ISRI may get a chance to test that claim: Deteriorating spawning grounds and unbridled poaching have reduced sturgeon stocks to a shadow of what they were a generation ago. With disaster looming, the two biggest fishing nations—Iran and Russia—are sparring over how many sturgeon are left and how to divvy up a declining catch. Amid the bickering, a new survey suggests that the sturgeon's free fall is continuing.

For most of the 20th century, Iran and the Soviet Union ran tight ships, at least on regulating sturgeon fisheries. The situation unraveled in 1991 when four Caspian states—Azerbaijan, Kazakhstan, Russia, and Turkmenistan—emerged from the Soviet collapse. Weak law enforcement and poverty along the Volga and Ural rivers, the northern spawning areas, have enabled poachers to take up to 10 times the legal catch. Despite the release of tens of millions of fingerlings each year, Caspian nations in 2004 caught only 760 tons of sturgeon, the smallest figure in a century, down from 26,600 tons in 1985.

Four Caspian sturgeon varieties—Russian, Persian, beluga, and stellate, or sevruga—supply 90 percent of the world's caviar. A fifth, the ship sturgeon, is so scarce that exporting its meat or caviar has been banned since 2002. Almost half of this year's caviar quota—51 of 105 tons—is Persian sturgeon, which mostly keeps to Iranian waters. Iranian officials attribute its relative robustness to government control of the caviar trade and zero tolerance for poaching.

But the Persian's rise has come at the expense of its kin, throwing the ecosystem off kilter, asserts marine ecologist Arash Javanshir of the University of Tehran. Besides fishing restrictions, he says, what's needed is a restoration program by the Caspian states that targets all sturgeon and their spawning grounds and many other organisms as well.



Caspian Sturgeon. Beluga, Russian, and stellate sturgeon are caught by Kazakh fishermen in the Ural River, possibly the last place where belugas reproduce in the wild.

CREDIT: SHANNON CROWNOVER, SEAWEB.
COURTESY OF CAVIAR EMPOR

fishers themselves, is conducive to neither 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 undermining its supporting ecosystems (6–11). 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 (12), 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 instead 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 **bycatch** to be only one component of the illegal, unreported, or unrecorded (IUU) catches that recently became part of the international fisheries research agenda (13–17).

The geographic and depth expansion of fisheries is easier to extrapolate (Figure 3). Over the past 50 years, fisheries targeting **benthic** and **benthopelagic** organisms have covered the shelves surrounding continents and islands down to 200 m, with increasing inroads below

KEY TERMS

Bycatch refers to species caught in a fishery that is targeting another species. Bycatch is often discarded and is usually dead or dying by the time it is returned to the sea.

The benthos is an aggregation of organisms living on or at the bottom of a body of water. **Benthic** organisms include infauna—the animals, and bacteria that live in the sediment; epifauna—organisms that are attached to or live on the hard-bottom or substrate (for example, rocks or debris); and demersals—the bottom-feeding or bottom-dwelling fishes that feed on the benthic infauna and epifauna.

Pelagic refers to the water columns of the ocean. The pelagic environment supports two types of marine organisms: microscopic plants and tiny animals that drift with the currents and make up the plankton, and the swimming nekton. The latter consists mainly of fishes and other vertebrates, such as turtles and marine mammals (e.g., seals, porpoises, and whales). Some invertebrate groups (e.g., squids and swimming crabs), contribute to the nekton.

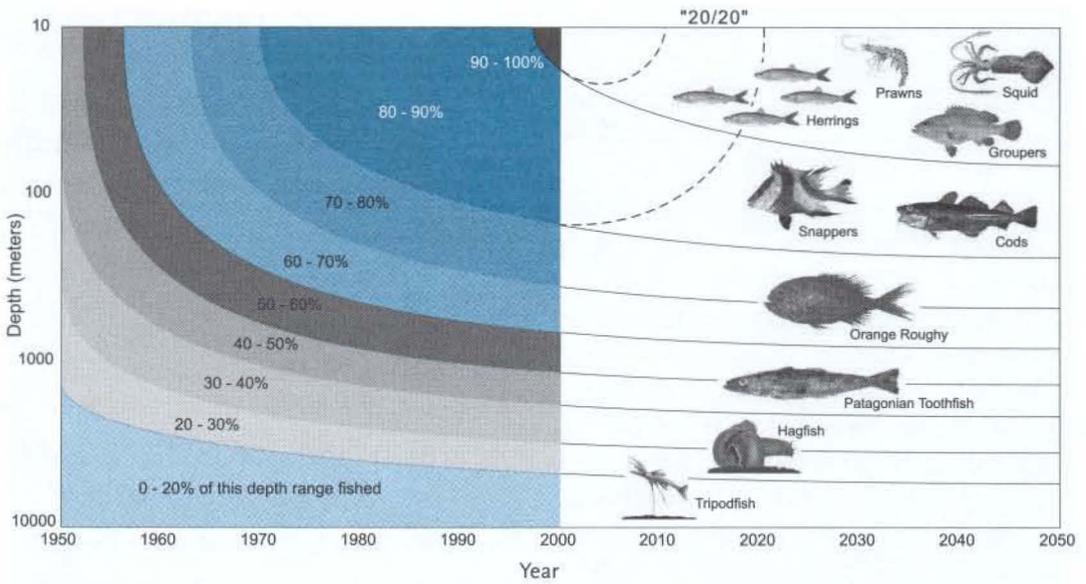


FIGURE 3. Fraction of the sea bottom and adjacent waters contributing to the world fisheries from 1950 to 2000 (38) and projected to 2050 by depth (logarithmic scale). Note the strong reversal of trends required for 20 percent of the waters down to 100-m depth to be protected from fishing by 2020.

1,000 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 (Figure 3). With satellite positioning and seafloor-imaging systems, we will deplete deep slopes, canyons, seamounts, and deep-ocean ridges of local accumulations of judiciously renamed bottom fishes—for example, orange roughy (previously “slimeheads”), Chilean seabass (usually IUU-caught Patagonian toothfish), and hagfish (caught for their “eel-skins,” and here predicted to become a delicacy in trendy restaurants, freshly knotted and sautéed in their own slime). The abyssal tripodfishes are the only group that seems safe so far. Figure 3 also shows the radical trend change required to turn 20 percent of the shallowest 100 m of the world ocean into marine reserves by 2020—that is, 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 (13, 18). Moreover, industrial fisheries depend upon cheap, seemingly superabundant fossil fuels (19, 20), as does agriculture. Thus, we shall here venture a prediction counter to the trends in Figure 3, based in part on the global oil production trend in Figure 4A. If fuel energy becomes increasingly scarce and expensive in the next decades as we move beyond the peak of global oil production, which is predicted to occur shortly by a number of independent geologists (21), then we should expect the least profitable of the energy-intensive industrial fisheries to fold (Figure 4B). This would mainly affect deep-sea bottom trawling, which drives the trends in Figure 3.

Any potential conservation benefits that might arise as a result of rising crude oil prices could be easily vitiated by increasing subsidies by short-sighted governments willing to accede to lobbying efforts from the fisheries sector. Barring escalating subsidies, one effect of high fuel prices may be to increase human consumption of small pelagics (mackerels, herrings, sardines, or

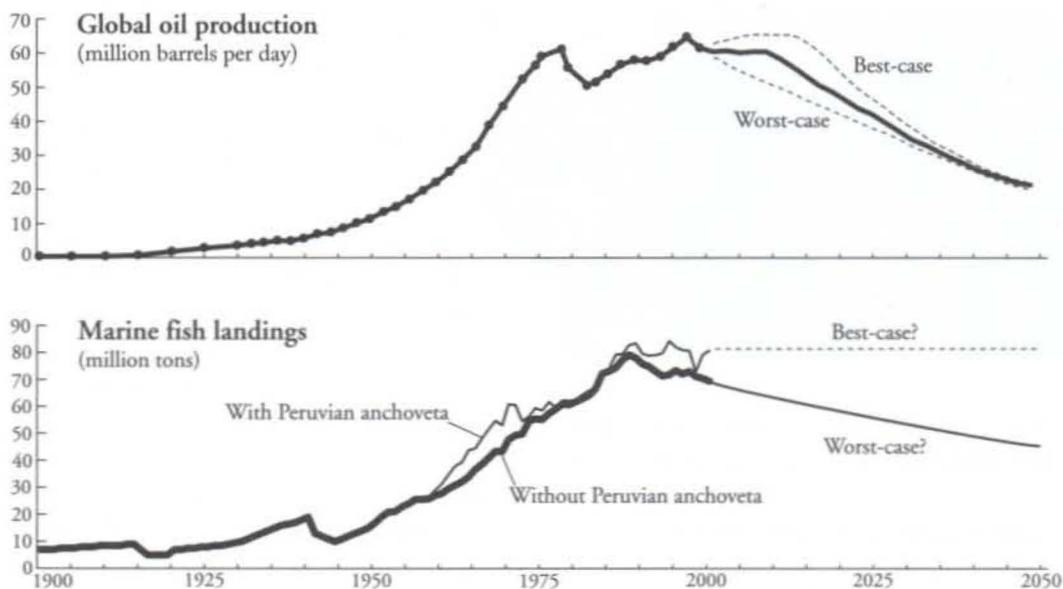


FIGURE 4. Recent historical patterns and near-future predictions of global oil production and fish catches (1900 to 2050). (A) Various authors currently predict global oil production to decline after ~2010 (21), based on M. King Hubbert's model of reservoir depletion, with worst, medium, and best cases 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—that is, sustaining present landings—would result from implementing proactive components of the Marketing First and Policy First scenarios.

anchovies such as the Peruvian anchoveta), which are now mostly turned into fish meal for agriculture (to raise chickens and pigs) and increasingly aquaculture (22).

However, predictions are better embedded into scenarios—sets of coherent, plausible stories designed to address complex questions about an uncertain future (23). 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.

In complement to the Millennium Ecosystem Assessment (24–27), we use the four scenarios developed by the United Nations Environment Programme (28) 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 (29, 30).

SCENARIO I. 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 in the same way that 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 (that is, areas not economically fishable, particularly

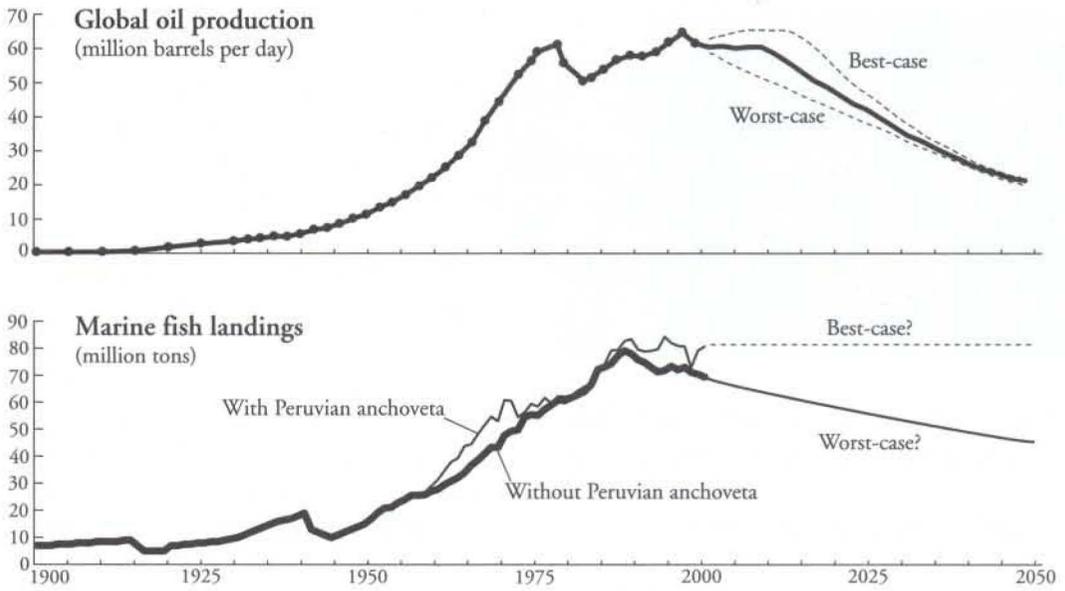


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Industrial fisheries depend upon cheap, seemingly super-abundant fossil fuels, as does agriculture.



offshore) and thus may reduce the impact of fishing 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 (29–31).

SCENARIO 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 those in the High Arctic, and subsidizing rich countries’ fleets to their logical ends, including the collapse of traditional fish stocks. This implies developing 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 eliminate 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 effects on the remaining marine fisheries in the host coun-

tries, 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: a large impact on biodiversity.

SCENARIO 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 (32), 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 (33).

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 bycatch (34)—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 (for example, shutting down profitable fisheries that kill sea turtles or marine mammals).

SCENARIO 4. Sustainability First requires a value system change to one that favors 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 carefully monitoring and rebuilding a number of major stocks (35, 36). This is because high biomasses provide the best safeguard against overestimates of catch quotas and

environmental change (13) (the latter is not covered here but is likely to affect 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 percent 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—for example, in the North Atlantic (18, 36) or the Gulf of Thailand (30, 31)—presently optimize nothing of benefit to society: not rent [taxable through auctions (37)], and not even gross catches (and hence long-term food and employment security). It is doubtful that they will be around in 2050.

References and Notes

1. The FAO regularly issues demand-driven global projections wherein aquaculture, notably in China, is assumed to compensate for shortfalls, if any, in fisheries landings (see www.fao.org).
2. J. G. Pope, *Dana* 8, 33 (1989).
3. R. H. Parrish, in *Global Versus Local Change in Upwelling Areas*, M. H. Durand et al., Eds. (Séries Colloques et Séminaires, Orstom, Paris, 1998), pp. 525–535.
4. D. Pauly, in *Ecological Integrity: Integrating Environment, Conservation and Health*, D. Pimentel, L. Westra, R. F. Ross, Eds. (Island Press, Washington, DC, 2000), pp. 227–239.
5. P. Cury, P. Cayré, *Fish Fish.* 2, 162 (2001).
6. D. Pauly, V. Christensen, *Nature* 374, 255 (1995).
7. D. Pauly et al., *Science* 279, 860 (1998).
8. J. B. C. Jackson et al., *Science* 293, 629 (2001).
9. R. A. Myers, B. Worm, *Nature* 423, 280 (2003).
10. R. Watson, D. Pauly, *Nature* 414, 534 (2001).
11. D. Pauly et al., *Philos. Trans. R. Soc. B* 360, 5 (2005).
12. R. L. Naylor et al., *Nature* 405, 1017 (2000).
13. D. Pauly et al., *Nature* 418, 689 (2002).
14. T. J. Pitcher et al., *Fish Fish.* 3, 317 (2002).
15. K. Kelleher, *Discards in the World's Marine Fisheries. An Update* (FAO Fisheries Technical Paper 470, 131 pp.) (2005).
16. Previous estimates for discards in the 1980s and 1990s were 27 million to 20 million tons, current estimates are 7.3 million tons; although not directly comparable, it is likely discards are lower than in earlier years (15). This implies that the decline of global fisheries estimated at 0.3 million tons per year (10) is actually two to three times higher (17).
17. D. Zeller, D. Pauly, *Fish and Fisheries*, 6, 156–159 (2005).
18. D. Pauly, J. Maclean, *In a Perfect Ocean: The State of Ecosystems and Fisheries in the Atlantic Ocean* (Island Press, Washington, DC, 2003).
19. P. Tyedmers, in *Encyclopedia of Energy*, C. Cleveland, Ed. (Elsevier, San Diego, CA, 2003), vol. 2, p. 683.
20. P. Tyedmers, R. Watson, D. Pauly, *Ambio* 34, 619–622 (2005).
21. R. Heinberg, *The Party's Over: Oil, War and the Fate of Industrial Societies* (New Society, Gabriola Island, BC, Canada, 2003).
22. C. Delgado, N. Wada, M. W. Rosegrant, S. Meijer, M. Ahmed, *Fish to 2020: Supply and Demand in Changing Global Markets* (International Food Policy Research Institute and WorldFish Center, 2003).
23. G. D. Peterson, S. R. Carpenter, G. S. Cumming, *Conserv. Biol.* 17, 358 (2003).
24. The four scenarios are *Global Orchestration* (economic growth and public goods focus on a global scale), *TechnoGarden* (green technology and continued globalization), *Order from Strength* (national security and economic growth focus at regional levels), and *Adapting Mosaic* (regionalized with emphasis on local adaptation and flexible governance). The focus on alternative approaches to sustaining ecosystem services distinguishes the Millennium Ecosystem Assessment (MA; see 25) scenarios from previous global scenario exercises.
25. The Millennium Ecosystem Assessment is an international work program designed to meet the needs of decision makers and the public for scientific information concerning the consequences of ecosystem change for human well-being and options for responding to these changes. See www.millenniumassessment.org.
26. R. Watson, J. Alder, V. Christensen and D. Pauly, "Mapping fisheries patterns and their consequences," pp. 13–33, in *Place Matters: Geospatial Tools for Marine Science, Conservation, and Management in the Pacific Northwest*, D. J. Wright, A. J. Scholz Eds (Univ. of Oregon, 2005).
27. E. M. Bennett et al., *Frontiers Ecol. Environ.* 1, 322 (2003).
28. United Nations Environment Program, *Global Environmental Outlook 3* (EarthScan, London, 2002).
29. This work was based on mass-balanced food web models and their time-dynamic simulation, through coupled differential equations, under the effects of

competing fishing fleets, using the Ecopath with Ecosim software, and models representing the South China Sea (with emphasis on the Gulf of Thailand and Hong Kong waters), the North Atlantic (North Sea, Faeroes), the North Pacific (Prince William Sound, Alaska, and Georgia Strait, British Columbia), and other marine ecosystems documented in www.ecopath.org and www.saup.fisheries.ubc.ca/report/report.htm.

30. V. Christensen, C. J. Walters. *Bull. Mar. Sci.* 74, 549 (2004).

31. V. Christensen. *J. Fish Biol.* 53 (Suppl. A), 128 (1998).

32. Pew Oceans Commission Report, *America's Living Oceans: Charting a Course for Sea Change* (2003).

33. T. Okey, *Mar. Policy* 27, 193 (2003).

34. L. Morgan, R. Chuenpagdee. *Shifting Gears: Addressing the Collateral Impacts of Fishing Methods in U.S. Waters* (Island Press, Washington, DC, 2003).

35. T. J. Pitcher, *Ecol. Appl.* 11, 606 (2001).

36. J. Alder, G. Lugten, *Mar. Policy* 26, 345 (2002).

37. S. Macinko, D.W. Bromley, *Who Owns America's Fisheries?* (Island Press, Washington, DC, 2002).

38. Disaggregated global landings assembled by the FAO from 1950 to 2000 were used to determine when each 30 min by 30 min spatial cell was first "fished" [i.e., when landings of fish (other than oceanic tuna and billfishes) from that cell first reached 10 percent of the maximum landings ever reported from that cell]. The percentage of cells fished at each depth was then calculated.

39. D.P., J.A., V.C., and R.W. are members of the Sea Around Us Project, initiated and funded by the Pew Charitable Trusts, Philadelphia. We thank A. Kitchingman and W. Swartz for help with the figures.

Web Resources

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