POLICY FORUM

ECOLOGY

Ecosystem-Based Fishery Management

E. K. Pikitch,[1*] C. Santora,[1] E. A. Babcock,[1] A. Bakun,[2] R. Bonfil,[3] D. O. Conover,[4] P. Dayton,[5] P. Doukakis,[1] D. Fluharty,[6] B. Heneman,[7] E. D. Houde,[8] J. Link,[9] P. A. Livingston,[10] M. Mangel,[11] M. K. McAllister,[12] J. Pope,[13] K. J. Sainsbury[14]

Many of the world's fish populations are overexploited, and the ecosystems that sustain them are degraded (*1*). Unintended consequences of fishing, including habitat destruction, incidental mortality of nontarget species, evolutionary shifts in population demographics, and changes in the function and structure of ecosystems, are being increasingly recognized.

Fisheries management to date has often been ineffective; it focuses on maximizing the catch of a single target species and often ignores habitat, predators, and prey of the target species and other ecosystem components and interactions. The indirect social and economic costs of the focus on single species can be substantial. For example, over 90% of the annual mortality of white marlin, a species petitioned for listing under the U.S. Endangered Species Act, occurs through incidental catch in swordfish and tuna longline fisheries. This threatens a recreational fishing industry worth up to U.S.$2 billion annually (*2*).

To address the critical need for a more effective and holistic management approach, a variety of advisory panels (*3*–*9*) have recommended ecosystem considerations be considered broadly and consistently in managing fisheries. Ecosystem-based fishery management (EBFM) is a new direction for fishery management, essentially reversing the order of management priorities to start with the ecosystem rather than the target species.

The overall objective of EBFM is to sustain healthy marine ecosystems and the fisheries they support. In particular, EBFM should (i) avoid degradation of ecosystems, as measured by indicators of environmental quality and system status; (ii) minimize the risk of irreversible change to natural assemblages of species and ecosystem processes; (iii) obtain and maintain long-term socioeconomic benefits without compromising the ecosystem; and (iv) generate knowledge of ecosystem processes sufficient to understand the likely consequences of human actions. Where knowledge is insufficient, robust and precautionary fishery management measures that favor the ecosystem should be adopted.

We need to derive and develop community and system-level standards, reference points, and control rules analogous to single-species decision criteria (*10*–*12*). We may want to ensure that total biomass removed by all fisheries in an ecosystem does not exceed a total amount of system productivity, after accounting for the requirements of other ecosystem components (e.g., nontarget species, protected species, habitat considerations, and various trophic interactions). Maintaining system characteristics within certain bounds may protect ecosystem resilience and avoid irreversible changes.

EBFM must delineate all marine habitats utilized by humans in the context of vulnerability to fishing-induced and other human impacts, identify the potential irreversibility of those impacts, and elucidate habitats critical to species for vital population processes. Protecting essential habitat for fish and other important ecosystem components from destructive fishing practices increases fish diversity and abundance (*13*, *14*). Thus, ocean zoning, in which type and level of allowable human activity are specified spatially and temporally, will be a critical element of EBFM.

The impacts of fisheries on endangered and protected species, including ecological processes that are essential for their recovery, should be managed through an EBFM approach. Single-species management has been successful at reducing incidental catch of protected species in some cases (e.g., with turtle excluder devices in trawls), but EBFM would also manage indirect effects (e.g., protecting forage fish near sea lion rookeries).

Another goal of EBFM is to reduce excessive levels of bycatch (i.e., killing of nontarget species or undersized individuals of the target species), because juvenile life stages and unmarketable species often play important roles in the ecosystem (*15*, *16*). Globally, discards in commercial fisheries have been estimated at 27.0 million metric tons, accounting for about one-fourth of the world's marine fish catch (*17*). Bycatch problems can be ameliorated through ocean zoning that would prohibit use of nonselective or destructive gear in critical areas, as well as through the development

[1]Pew Institute for Ocean Science, Rosenstiel School of Marine and Atmospheric Science (RSMAS), University of Miami, New York, NY 10022, USA. [2]RSMAS, University of Miami, Miami, FL 33149–1098, USA. [3]Wildlife Conservation Society, Bronx, NY 10460, USA. [4]Marine Sciences Research Center, Stony Brook University, Stony Brook, NY 11794–5000, USA. [5]Scripps Institution of Oceanography, La Jolla, CA 92093–0227, USA. [6]School of Marine Affairs, University of Washington, Seattle, WA 98105, USA. [7]Commonweal Ocean Policy Program, Bolinas, CA 94924, USA. [8]University of Maryland Center for Environmental Science, Chesapeake Biological Laboratory, Solomons, MD 20688, USA. [9]Food Web Dynamics Program, National Marine Fisheries Service—Northeast Fishery Science Center, Woods Hole, MA 02543, USA. [10]Alaska Fisheries Science Center, Seattle, WA 98115, USA. [11]Department of Applied Mathematics and Statistics, Jack Baskin School of Engineering, University of California, Santa Cruz, CA 95064, USA. [12]Department of Environmental Science and Technology, Imperial College, Royal School of Mines Building, Prince Consort Road, London SW7 2BP, UK. [13]National Research Council (Europe) Ltd., Norfolk NR34 OBT, UK. [14]Division of Marine Research, CSIRO, Tasmania 7001, Australia.

*Author for correspondence. E-mail: epikitch@rsmas.miami.edu

and deployment of more selective and less damaging fishing technologies.

Finally, EBFM must manage target species in the context of the overall state of the system, habitat, protected species, and nontarget species. Single-species target and limit reference points are still appropriate, but will need to be modified in the context of these other factors.

We believe EBFM can be implemented in systems that differ in levels of information and uncertainty (*18*) through the judicious use of a precautionary approach. This means erring on the side of caution in setting management targets and limits when information is sparse or uncertain. Greater uncertainty would be associated with more stringent management measures. Because ecosystem management involves a wide range of objectives, great ecosystem complexity, and a high level of uncertainty in predicting impacts, EBFM inevitably requires that some level of precaution be exercised. Ideally, EBFM would shift the burden of proof so that fishing would not take place unless it could be shown not to harm key components of the ecosystem.

In data-poor situations with little or no information about target species status or ecosystem processes, EBFM may simply involve using natural history and general knowledge to develop precautionary set-asides or safety margins, such as reduced catch limits or larger closed areas. In systems with moderate amounts of data (e.g. catch data and abundance trends for key species), EBFM could be characterized by effective single-species management with the addition of precautionary set-asides for unknown ecosystem components.

Targeted management and improved data collection (ecosystem-based reference points and measures of system status) for high-priority ecosystem interactions could promote more comprehensive EBFM in the future. With increased richness of data, management evolves toward a system in which performance indicators for each ecosystem-based objective are monitored. With more data, there could be fewer precautionary measures.

Progression from data-poor to data-rich EBFM will be facilitated by adaptive management (*19*) and greater understanding of how ecosystems respond to alternative fishing strategies. For example, areas could be set aside as controls to measure the impact of fishing on benthic communities (*13*, *18*). In addition, EBFM should be tailored to the management capacity available and to allow for sequential improvements.

New analytical models and management tools will be needed as well. Multispecies and eco-trophic models (*20*–*22*) must be refined and expanded to better account for system-level uncertainties, to derive system-level reference points, and to evaluate the ecosystem-level consequences of proposed EBFM actions (*19*, *23*). Because EBFM emphasizes habitat and ecosystem function in the context of fluctuations, advanced models for EBFM should incorporate spatial structure and environmental processes.

EBFM may require evolution from suites of single-species fishery management plans to integrated ecosystem-based fishery management plans (EBFMP). In an EBFMP, the impact of a management action would be assessed with respect to the ecosystem as well as individual species. It is entirely possible that a fishery could be considered overfished within the ecosystem plan (ecosystem overfishing) when it is not overfished in a single-species context. This can occur when a forage species that serves as a prey resource for marine predators is also the target of a fishery or when overfishing of large predators causes food web shifts (*24*).

Rebuilding ecosystems from their degraded state, in turn, might inflict short-term economic hardship on fishers. The transition to EBFM might thus involve compensating fishers and providing incentives to other stakeholders to support EBFM as a long-term strategy. For example, compensation (in the form of a quota buy-out scheme) was a principal mechanism used to encourage fishers to accept a radical shift in fishery management policy [individual transferable quotas (ITQs)] in New Zealand (*25*).

It will not be easy to make the transition from an established management system based on maximizing individual species yield to an ecosystem-focused approach that acknowledges the uncertainty inherent in marine ecosystems. The difficulties are not insurmountable, however, and should not delay progress.

EBFM should move forward now despite current uncertainties about ecosystems and their responses to human actions because the potential benefits of implementation are as large as or greater than the potential risks of inaction. This has already begun in California's nearshore fishery, where precautionary restrictions have been placed on allowable catches, with the understanding that they can be eased as ecosystem-related information increases (*18*). In Alaska, management regulations already include ecosystem-based fishery management measures such as control of directed and incidental catches; a prohibition on fishing of forage species (on which other fish, seabirds, and marine mammals depend); protection of habitat for fish, crabs and marine mammals; and temporal and spatial controls of fishing (*26*). Legislation to implement the recommendations of the Pew Oceans Commission and U.S. Commission on Ocean Policy, including legislation calling for ecosystem-based management is being drafted in both the House and the Senate and will likely be introduced this summer. Internationally, ecosystem-based approaches are being discussed in many forums. They are currently being considered as a means to meet the commitments on fisheries made at the 2002 World Summit on Sustainable Development. We would urge that the principles described here be made the cornerstone of these and other efforts.

References and Notes

1. Food and Agriculture Organization (FAO) Fisheries Department, *The State of World Fisheries and Aquaculture* (FAO, Rome, 2002).
2. Petition for the listing of the Atlantic White Marlin as a threatened or endangered species. Filed under 5 U.S.C. § 553 (e), 16 U.S.C. § 1533, and 50 C.F.R. §§ 424.14, 424.10 by Biodiversity Legal Foundation and J. R. Chambers (31 August 2001).
3. Ministry of the Environment, Intermediate Ministerial Meeting on the Integration of Fisheries and Environmental Issues, "Statement of conclusions" (Ministry of the Environment, Oslo, 1997).
4. Ecosystem Principles Advisory Panel, "Ecosystem-based fishery management: A report to Congress by the Ecosystem Principles Advisory Panel" (U.S. National Marine Fisheries Service, 1999).
5. National Research Council, *Sustaining Marine Fisheries* (National Academy Press, Washington, DC, 1999).
6. FAO Fisheries Department, *FAO Tech. Report No. 4* (Suppl. 2) (2003).
7. House of Lords, "Fish Stock Conservation and Management. Session 1995–96." *House of Lords Paper* **25** (1996).
8. U.S. Commission on Ocean Policy, "Preliminary Report of the U.S. Commission on Ocean Policy, Governor's Draft" (U.S. Commission on Ocean Policy, Washington, DC, April 2004).
9. Pew Oceans Commission, "America's Living Oceans: Charting a Course for Sea Change. A Report to the Nation." (Pew Oceans Commission, Arlington, VA, 2003).
10. J. C. Rice, *ICES J. Mar. Sci.* **57**, 682 (2000).
11. S. A. Murawski, *ICES J. Mar. Sci.* **57**, 649 (2000).
12. J. S. Link *et al.*, *Can. J. Fish. Aquat. Sci.* **59**, 1429 (2002).
13. K. J. Sainsbury, R. A. Campbell, R. Lindholm, W. Whitelaw, *Am. Fish. Soc. Symp.* **20**, 107 (1997).
14. C. M. Roberts, J. A. Bohnsack, F. Gell, J. P. Hawkins, R. Goodridge, *Science* **294**, 1920 (2001).
15. J. G. Pope *et al.*, *ICES J. Mar. Sci.* **57**, 689 (2000).
16. L. T. Ballance, R. L. Pitman, S. B. Reilly, *Ecology* **78**, 1502 (1997).
17. D. Alverson, *Am. Fish. Soc. Symp.* **20**, 115 (1997).
18. L. Kaufman, B. Heneman, J. T. Barnes, R. Fujita, *Bull. Mar. Sci.* (in press).
19. K. J. Sainsbury, A. E. Punt, A. D. M. Smith, *ICES J. Mar. Sci.* **57,** 731 (2000).
20. A. B. Hollowed *et al.*, *ICES J. Mar. Sci.* **57**, 707 (2000).
21. R. J. Latour, M. J. Brush, C. F. Bonzek, *Fisheries* **28**, 10 (2003).
22. S. J. Whipple, J. S. Link, L. P. Garrison, M. J. Fogarty, *Fish Fish.* **1**, 22 (2000).
23. A. D. M. Smith, K. Sainsbury, R. Stevens, *ICES J. Mar. Sci.* **56**, 967 (1999).
24. H. Gislason, in *Responsible Fisheries in the Marine Ecosystem*, M. Sinclair and G. Valdimarsson, Eds. (FAO, Rome, and CABI Publishing, Wallingford, UK, 2003).
25. P. Major, *Am. Fish. Soc. Symp.* **20**, 264 (1997).
26. D. Witherell, C. Pautzke, D. Fluharty, *ICES J. Mar. Sci.* **57**, 771 (2000).

27. Initiated and funded by the Pew Charitable Trusts through a grant to the Wildlife Conservation Society. At project inception, authors Pikitch, Babcock, Santora, and Doukakis were employed by the Wildlife Conservation Society. The views and recommendations contained in this paper are those of the authors and do not necessarily reflect the views of their affiliation or employer.