Current Problems in the Management of Marine Fisheries

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The public perception of fisheries is that they are in crisis and have been for some time. Numerous scientific and popular articles have pointed to the failures of fisheries management that have caused this crisis. These are widely accepted to be overcapacity in fishing fleets, a failure to take the ecosystem effects of fishing into account, and a failure to enforce unpalatable but necessary reductions in fishing effort on fishing fleets and communities. However, the claims of some analysts that there is an inevitable decline in the status of fisheries is, we believe, incorrect. There have been successes in fisheries management, and we argue that the tools for appropriate management exist. Unfortunately, they have not been implemented widely. Our analysis suggests that management authorities need to develop legally enforceable and tested harvest strategies, coupled with appropriate rights-based incentives to the fishing community, for the future of fisheries to be better than their past.

The United Nations Food and Agriculture Organization (FAO), which monitors the state of world fisheries, has estimated that since 1990 approximately one-quarter of fish stocks have been overexploited, depleted, or are recovering from depletion (17%, 7%, and 1%, respectively) (*1*), with the Northeast and Northwest Atlantic, the Mediterranean, and the Black Sea being the areas with the largest number of depleted stocks (*2*). Many authors have elaborated on these conclusions, documenting the poor state of fisheries worldwide (*3*). Nevertheless, the situation, although serious, is not catastrophic, and there are grounds for optimism. There have been successes of fisheries management, and there is an understanding of what is involved in successful fisheries management and of the requirements for its implementation. These issues are explored in this review.

The management of commercial fisheries clearly requires a good scientific understanding of the behavior of the exploited stock or stocks. The science that is used to assess commercially exploited species is still dominated by the population models developed by Beverton and Holt for single-species assessments some 50 years ago (*4*). The availability of substantial computing power has meant that sophisticated estimation methods can be used, and an appreciation of the way in which fish stocks respond to environmental variability is readily incorporated in scientific advice (*5*). Calls for a more ecosystem-orientated approach have been voiced for some while, but the paucity of data and the demands of multiparameterized multispecies models means that most ecosystem considerations in practical stock assessment tend to be ad hoc manipulations of the single-species approach (*6*).

What has developed is a realization that effective management requires an understanding of how the fishery system is performing relative to reference points. The most commonly used reference points are those relating to the size of the stock itself and the fishing mortality that will result in these stock sizes, given existing relationships between the stock, recruitment, natural mortality, and growth (Fig. 1). A typical "target reference point" is the biomass necessary to produce maximum sustainable yield (BMSY). However, such targets do not explicitly recognize threats to the stock. To address this issue, stock size "limit reference points" are usually defined or interpreted as the stock biomass below which recruitment becomes substantially reduced. Clearly, it is important to avoid situations where the stock is at or below this level. Accordingly, management should aim to have as a target a level of stock size that carries a low risk (allowing for scientific uncertainty) of the stock dropping below the limit reference point (*7*). This could mean having a target level of fishing mortality that provides stock sizes above BMSY.

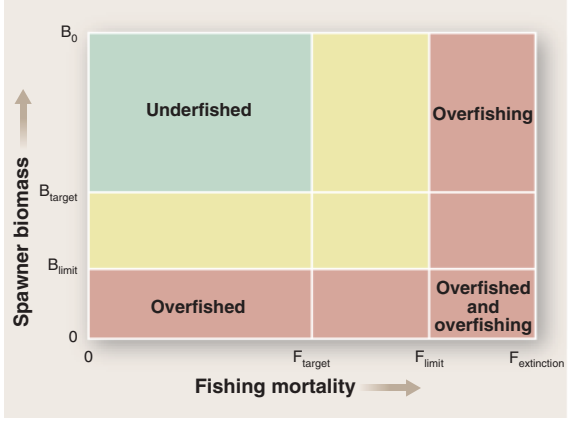

Fig. 1. Typical reference points and stock status definitions for stock biomass and fishing mortality. The limit of fishing mortality that generates biological extinction is F extinction.

Understanding Fisheries Management

Competent scientific advice based on appropriate data is far from ubiquitous in the fisheries world, and even in ideal situations, fisheries management has often been unsuccessful. The success of a management system is often defined in terms of biological, economic, social, and political objectives. Clearly, economic and social objectives will not be met while a stock is in such a depleted state that the long-term sustainability of the fishery is threatened, but equally, biological objectives are unlikely to be met without consideration being given to economic and social objectives. Hence, we argue that an understanding of the fishery management process can only come from analyzing the capacity and incentives of the two key stakeholders: the fishing community and the management authority. This is not to belittle the importance of other stakeholders, such as recreational fishers and environmental groups, who have important roles in the management of certain fisheries.

Where management is weak or nonexistent, the economic factors underlying overfishing in commercial fisheries have been generally understood since the 1950s (*8*). In short, when multiple fishers compete to catch fish from a given population, each fisher maximizes his net income by continuing to fish as long as the value of his catch exceeds the cost of catching it. An equilibrium, called the bionomic equilibrium, is reached only when fishing has reduced the fish population to a level at which catch rates are barely sufficient to cover the costs of fishing. The population is then maintained at this level through biological processes of natural growth and reproduction. Thus, if the price:cost ratio is high, the bionomic equilibrium will result in a low stock of fish, and hence a low annual catch level; two characteristic features of overfishing. In addition, the so-called economic rents (total revenue minus total costs) from the fishery will equilibrate at zero, resulting in minimal overall economic efficiency.

Many management authorities seek to meet their objectives by setting output controls in terms of a total allowable catch (TAC) for the year and closing the fishery when the year's cumulative catch has reached the TAC. Restrictions on fishing gear, fishing season, and fishing areas, as a supplement to the TAC, may also be imposed. If the TAC is correctly specified and enforced, this

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method should maintain a stock level well above that of bionomic equilibrium. If, however, the TAC and the science behind it are not respected by fishermen and not adequately enforced by authorities, widespread illegal fishing can occur. A recent example is in the eastern Baltic cod fishery where illegal fishing contributes to true catches being some 35 to 40% higher than reported (*9*).

Efficient enforcement can be difficult. Put simply, fishers will be deterred from breaking fishing regulations if their expected loss from detection and successful prosecution exceed their expected gain. In many fisheries, the probability of detection of illegal activity and the penalties are not sufficiently high to act as a disincentive (*6*).

Strong management can ensure that biological targets are met, but it is essential that regulations are enforceable, and this has often proved to be difficult. Less-than-perfect enforcement can lead to illegal fishing, poor scientific data, and a failure to meet biological targets. Input measures, such as limiting the number of vessels or restricting available season length, are usually more easily enforceable than output measures such as TAC (*10*). However, control via input measures is vulnerable to effort creep, whereby operators increase the fishing power of their vessels through technical means. Nevertheless, monitoring of vessel performance over time and adjusting the allowable level of effort have allowed successful effort control to be implemented (*11*).

Overcapacity

Simplistically, it would seem that positive economic rents should also emerge in a TAC-regulated fishery. In reality, many TAC-regulated fisheries have experienced an unexpected increase in fishing capacity, as additional vessels enter the fishery in response to (temporarily) positive rents. Economic models (*12*, *13*) then predict a regulated bionomic equilibrium, in which economic rents (net of fixed costs) again equilibrate at, or near, zero. This situation currently exists in many of the world's regulated fisheries; overcapacity of fishing fleets is widely perceived as a major impediment to achieving economically productive fisheries (*14*). It is thus ironic that such overcapacity is usually generated by the management system itself, although it can also result from high profitability during the initial phase of a newly developing fishery.

Overcapacity is widely recognized as a major problem affecting world fisheries. With its attendant social and economic problems, overcapacity can, via the political process, lead to the erosion of management control (*15*). It is also understood to be one of the results of subsidizing fisheries, which even today is estimated to be several tens of billion U.S. dollars per year (*16*). Such subsidies directly undermine the sustainability of fisheries because they lead to a bioeconomic equilibrium with high levels of fishing and low stock size. In several fisheries, government funds have been used to buy out excess fishing capacity. For various reasons, such buyback programs have been less effective than expected. First, often only the least efficient vessels are bought up, leaving total fishing capacity largely intact. Second, the buyback program by itself does not remove the economic incentives underlying overcapacity, which tends to increase once the buybacks are completed (*12*, *17*).

Thus, the underlying cause of the dual crisis of overfishing and overcapacity, as well as other undesirable outcomes, such as habitat destruction and incidental kills of untargeted species, can be found in the economic incentives of fishers who compete for their annual catches. These incentives are not affected by management strategies that retain the competition between fishers for a common-pool resource. Perhaps the most important development in fisheries management over the past 20 years has been the recognition of this fact and the introduction of rights-based management in several regimes. Indeed, it has been argued that of the tools at the disposal of managers, more emphasis needs to be placed on incentive-based approaches that better specify community and individual harvest or territorial rights, in additional to public research, monitoring, and effective administrative oversight (*18*).

Transferable Quotas

An alternative management strategy based on individually allocated transferable annual catch quotas (ITQs, or individual transferable quotas) is now in effect in several fishing nations, including Australia, New Zealand, Iceland, Canada, and Namibia. A well-organized rights system alters the economic incentives of fishers, who no longer compete for their catches, so that highly competitive fishing no longer takes place. The guarantee to fishers of a certain proportion of the catch allows them to make rational economic choices about where and when they catch fish. An ITQ system goes further, allowing the industry to settle on a fleet capacity that optimizes individual economic yield to vessels or cooperatives, although this of course can still be distorted by inappropriate subsidies.

In addition, ITQ fishers may often be expected to favor management actions that protect and enhance fish populations, because the value of a quota share increases as stocks become more abundant. Problems that may arise, such as misreporting or high-grading of catches, have been successfully countered by the use of observers, required by the management system but paid for by the industry; observers are used extensively in the U.S. Pacific fisheries, Australia, and New Zealand. Experience with ITQ systems shows that many fishers willingly support and adhere to conservative management strategies and may also avoid fishing practices that endanger habitat or threaten other species, so long as they are guaranteed long-term rights. But this does not mean that enforcement and scientific monitoring are unnecessary in ITQ systems; both are essential unless catch levels are set at precautionary low levels. It is thus unsurprising that the two countries with perhaps the most fully developed ITQ systems, New Zealand and Iceland, have some of the highest costs of management per fishing vessel (*19*)

Several authors have pointed to instances of successful fisheries management in both the developed (*20*, *21*) and developing (*22*) world. Among their conclusions are that incentive structure, institutional capacity, and participation of stakeholders are of key importance. However, in some studies, a rights-based approach is seen as the primary mechanism to deliver this (*18*), whereas in others, severe top-down controls with very limited participation of fishing communities in the management process are advocated (*23*). We argue here that a necessary condition for successful management contains all these elements: a competent management authority able to set and enforce regulations and monitor the status of the stock, together with some form of rights-based allocation to fishing operators (either collectively or individually) to avoid the situation where overcapacity produces economic hardship and erodes management capacity.

Evidence from Fisheries Performance

Reviews of successful fishery management are of necessity specific to individual fisheries and sometimes anecdotal. However, in some large areas, a combination of strong state governance and wealth, substantial scientific activity, and different types of fishery management offer the opportunity of some comparison between different types of fishery management that goes beyond the anecdotal.

Detailed data on the status of different fisheries are published for U.S., Northeast Atlantic, Australian, and New Zealand fisheries. The approach to management taken by these authorities is varied. New Zealand has the most developed and widespread application of individual user rights (ITQs), which have been in place from 1986 and have spawned other developments such as collaborative and alternative research by stakeholders (*24*). ITQs are present also in some Australian fisheries, a very few U.S. fisheries, and some Northeast Atlantic fisheries. (The Faroes, Norway, Iceland, and United Kingdom have rights-based systems, and some fleets, notably the Dutch flatfish and Spanish Grand Sole fleets, are also managed via ITQ.)

If a broad view is taken of these management areas, the evidence for the positive benefits of ITQs in supporting sustainable resource use is mixed. Only 15% of New Zealand's stocks within the quota management system, for which the stock status is known, are substantially below the target reference level. For other administrations, the percentage of stocks that are below the limit reference level (i.e., overfished), out of the total number of stocks for which the status is currently

known, is 19% for Northeast Atlantic fisheries managed by non–European Union (EU) administrations (Iceland, Faroes, and Norway), 25% for federally managed U.S. fisheries, 30% for Northeast Atlantic fisheries managed primarily by the EU, and 40% for Australian Commonwealth fisheries (*25*, *26*) (see supporting online material). Even within the United States, there are very large regional differences: 40% of major Fish Stock Sustainability Index (FSSI) stocks managed by the New England and Mid-Atlantic Fishery Management Councils, for which the stock status is known, are overfished, and 30% are subject to overfishing. By contrast, only 13% of FSSI stocks managed by the Pacific, West Pacific, and North Pacific Management Councils are overfished, with 6% suffering from overfishing.

Only the United States has seen an improvement in performance over the past several years; in 2000, 38% of U.S. stocks for which the status was known were classified as overfished. All other areas have experienced some increases in the number of overfished stocks in the past decade, although the increases in New Zealand have been very small and are offset by recoveries in some inshore stocks. However, these statistics disguise a quite dynamic situation within each region; for example, of 74 U.S. stocks requiring rebuilding, biomass is increasing in 48% of them even if they have not yet achieved rebuilt status (*27*).

More detailed examination of the U.S. situation reveals that although ITQs are not generally applied, West Coast fisheries are managed by quota controls with fishing rights assigned to fishing companies or sectors, whereas in the northeast, fisheries are managed by a days-at-sea scheme and other effort controls (*28*). In terms of their current performance and the stock recovery required by the Magnusson-Stevens Act, West Coast management systems appear to be more effective than northeast coast systems: Only two of the 18 New England stocks that were overfished in 1995 have now recovered, compared to 4 of 9 stocks similarly categorized by the Pacific Fisheries Management Council (*27*).

Clearly, non-ITQ management systems do not always fail to maintain sustainable stocks, and management systems using ITQs are not always successful. The critical additional requirement appears to be a formally adopted management strategy with predefined rules for what to do in different circumstances. In New Zealand, in addition to an ITQ system, a formal harvest strategy embedded in the Fisheries Act (1996) means that rebuilding is statutorily required when the stock is below its target level (*29*). By contrast, the lack of a formally adopted harvest strategy in the Australian Southern and Eastern Scalefish and Shark fishery has led to an increase in the number of overfished stocks in that fishery over the past 10 years, despite operating with an ITQ system since 1992 (*30*). EU fisheries also lack a formal harvest strategy; although there is a commitment under the 2002 revision of the Common Fisheries Policy to develop multiannual management plans for all stocks, such plans are only currently defined for 17 of the 94 stocks that fall under EU management, and many of these have had to be negotiated during periods of stock collapse.

The key problems, i.e., the need to provide incentives to fishers to engage constructively in fisheries management and the need to have strong legal support for predefined harvest strategies, apply equally to management of stocks under national control and those in international waters under the control of Regional Fisheries Management Organisations. To our knowledge, none of the latter currently allocate rights to individual fishers, and only a few have defined and tested effective harvest strategies. Allocation problems continue to beset these high-seas fisheries and influence compliance, data availability, and transparency (*31*–*33*).

Ultimately, the most successful management approaches are likely to combine rights-based systems, creating incentives for fishers to operate efficiently and with long-term sustainability in mind, with a strong legal structure that requires the development of pre-agreed harvest strategies and decision rules that are triggered and adhered to as reference points are passed. As indicated earlier, an adequate control of fishing activities is also necessary (*19*).

Addressing Ecosystem-Based Management

In recent years, there have been many calls for much wider use of Marine Protected Areas to address the need for ecosystem-based management. We see these as a useful part of fishery regulation, but they are not a universal solution because unless the basic issues of capacity, regulation, and rights are solved, protected areas will simply displace the problem elsewhere. In this

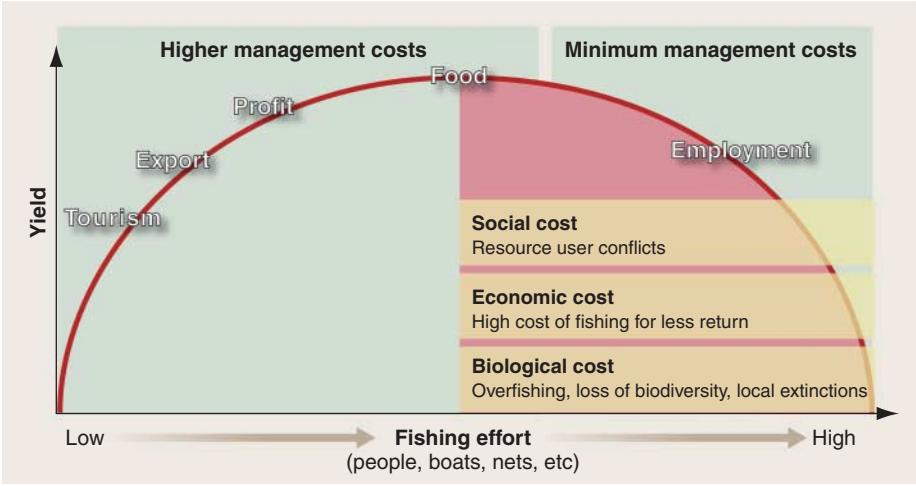

Fig. 2. The fishery management dilemma is illustrated with a simple stock production curve showing sustainable yield varying with effort. Low effort reduces biological risks and enhances economic profits at the cost of low employment and higher management costs. High effort increases employment at the cost of low economic profits and increased biological and social risks, but with low management costs (*40*).

The recovery of depleted fish stocks is a key issue and one to which most countries committed themselves in 2002 as part of the World Summit on Sustainable Development. An effective reduction in fishing effort, the participation of fishers and other stakeholders in the science and decision-making process, and the biology of the species are important factors affecting successful recovery (*34*). However, unless a harvest strategy is defined, with pre-agreed, legally binding decision rules requiring reductions of effort when stock sizes decline below limit reference points, most management authorities will still delay taking action to recover stocks. Some of this delay may arise from uncertainty in the science, but mostly it arises from an unwillingness to take decisions that will create hardship for fishers, and usually a delay will exacerbate stock decline (*35*).

we concur with recent reviews (*18*, *20*, *36*, *37*) that emphasize the primary importance of conventional measures to control fishing mortality and the secondary but essential role that marine protected areas (or other area-based management, such as local prohibitions on particular gears such as bottom trawls) have in dealing with specific issues of ecosystem conservation, such as bycatch and habitat damage.

The simple creation of rights-based incentives does not automatically deal with ecosystem problems, because fishers have little incentive to minimize bycatch or habitat damage that does not affect their target species. An interesting recent development is the creation of additional incentives for fishers through market measures, such as the creation of sustainable fisheries certification schemes and pressure from environmental nongovernmental organizations for responsible fisheries. Fishers have a major incentive to im-

prove fisheries to satisfy certification conditions, and so far most of the conditions raised in Marine Stewardship Council certifications have concerned the ecosystem effects of fishing, often related to quantifying and reducing deaths of bycatch species and damage to habitat (see supporting online material).

Even in the statistics documented for some of those states with appreciable management capacity, what is striking is for how many stocks, the status is uncertain or not determined. In the United States, the stock status of 30% of the 230 major (FSSI) stocks and stock complexes was undetermined in 2006; in Australia (48%), New Zealand (78%), and the Northeast Atlantic (61%), the numbers are even higher (*38*).

Given the problems that most authorities have in deriving reliable quantitative assessments of their stocks of major commercial importance, the large numbers of small, commercially unimportant stocks present in most areas, usually as bycatch, cannot realistically be assessed. Under a comprehensive ecosystem approach, risk assessment methodologies should be used to identify those bycatch species in need of special measures (*39*), and monitoring programs, for instance using scientific observers, need to be implemented to monitor trends in all bycatch species. The application of these approaches is in its infancy even in the most advanced management schemes; many simply respond by setting untested but hopefully precautionary effort or catch limits (*10*).

These considerations apply even more strongly to fisheries operators in developing countries. In a situation of little or no management capacity, some form of bioeconomic equilibrium is the likely result, but in such cases the management priorities may be different. Indeed, high employment with relatively modest economic rent, as long as it is compatible with the sustainability of the resource, may be a perfectly legitimate management goal (Fig. 2). In other cases, the development of Territorial Use Rights (TURFS) within local communities can lead to effective management control and rights-based operations, resulting in successful management (*20*, *21*).

Concluding Remarks

There is no doubt that there is a major problem with the world's fisheries, and, despite serious attempts to improve management and to facilitate recovery of depleted stocks, the success has been limited. The key issue that we highlight in this review is that for successful management a dual approach is required, one in which authorities provide incentives for conservation based on fishers' rights and which is supported by strong management incorporating legally enforced and tested harvest strategies.

References and Notes

1. FAO, *The State of World Fisheries and Aquaculture 2006* (FAO Fisheries Department, Rome, 2007).
2. S. M. Garcia, J. R. Grainger, *Philos. Trans. R. Soc. London B Biol. Sci.* **360**, 21 (2005).
3. D. Pauly, J. Maclean, *In a Perfect Ocean: The State of Fisheries and Ecosystems in the North Atlantic Ocean* (Island Press, Washington, DC, 2003).
4. R. J. H. Beverton, S. J. Holt, *MAFF Fish. Invest. London Ser. 2* **19**, 1 (1957).
5. T. J. Quinn II, R. B. Deriso, *Quantitative Fish Dynamics* (Oxford Univ. Press, Oxford, 1999).
6. J. R. Beddington, G. P. Kirkwood, in *Theoretical Ecology: Principles and Applications*, R. M. May, A. R. McLean, Eds. (Oxford Univ. Press, Oxford, 2007), pp. 148–157.
7. P. M. Mace, *Can. J. Fish. Aquat. Sci.* **51**, 110 (1994).
8. H. Scott Gordon, *J. Polit. Econ.* **62**, 124 (1954).
9. ICES, *Report of the Baltic Fisheries Assessment Working Group* (International Council for the Exploration of the Sea, CM 2006/ACFM:24, Copenhagen, 2006).
10. J. G. Shepherd, *Fish. Res.* **63**, 149 (2003).
11. A. J. Barton, D. J. Agnew, L. V. Purchase, in *Management of Shared Fish Stocks*, A. I. L. Payne, C. M. O'Brien, S. I. Rogers, Eds. (Blackwell, Oxford, UK, 2004), pp. 202–222.
12. C. W. Clark, *The Worldwide Crisis in Fisheries: Economic Models and Human Behavior* (Cambridge Univ. Press, Cambridge, UK, 2007).
13. C. W. Clark, *Mathematical Bioeconomics: The Optimal Management of Renewable Resources* (Wiley Interscience, New York, 1990).
14. M. H. Tupper, *Science* **295**, 1233 (2002).
15. C. Safina, A. A. Rosenberg, R. A. Myers, T. J. Quinn II, J. S. Collie, *Science* **309**, 707 (2005).
16. ICTSD, *Fisheries, International Trade and Sustainable Development: Policy Discussion Paper* (International Centre for Trade and Sustainable Development, Geneva, Switzerland, 2006).
17. C. W. Clark, G. R. Munro, U. R. Sumaila, *J. Environ. Econ. Manage.* **50**, 47 (2005).
18. R. Q. Grafton *et al.*, *Can. J. Fish. Aquat. Sci.* **63**, 699 (2006).
19. OECD, *The Cost of Managing Fisheries* (Organization for Economic Cooperation and Development, Paris, 2003).
20. R. Hilborn, *Ambio* **36**, 296 (2007).
21. R. Hilborn, J. M. Orensanz, A. M. Parma, *Philos. Trans. R. Soc. B* **360**, 47 (2005).
22. S. Cunningham, T. Bostock, Eds., *Successful Fisheries Management: Issues, Case Studies and Perspectives* (Eburon, Delft, Netherlands, 2005).
23. Pew Ocean Commission, "America's living oceans: Charting a course for sea change" (Pew Oceans Commission, Arlington, VA, 2003); available at www-ocean.tamu.edu/GOOS/GSC8/nowlin.ppt.
24. I. Del Valle, E. Hoefnagel, K. Astorkiza, I. Astorkiza, in *The Knowledge Base for Fisheries Management*, L. Motos, D. C. Wilson, Eds. (Elsevier, Amsterdam, 2006), pp. 55–83.
25. "Status of U.S. Fisheries 2006" (NOAA Fisheries, Office of Sustainable Fisheries); available at www.nmfs.noaa.gov/sfa/statusoffisheries/SOSmain.htm.
26. K. McLoughlin, *Fishery Status Reports 2005: Status of Fish Stocks Managed by the Australian Government* (Bureau of Rural Sciences, Canberra, 2007).
27. A. A. Rosenberg, J. H. Swasey, M. Bowman, *Front. Ecol. Environ.* **4**, 303 (2006).
28. See (*27*) and the New England Fishery Management Council (NEFMC) 2006 consultation document on the Magnusson-Stevens Act reauthorization (available at www.nefmc.org/nemulti/A16_scoping_final.pdf).
29. Ministry of Fisheries, "Report from the Fishery Assessment Plenary, May 2006: Stock assessments and yield estimates" (Ministry of Fisheries, Wellington, New Zealand, 2006); available at www.fish.govt.nz/en-nz/SOF/default.htm.
30. See (*26*). Note, however, that Australia is in the process of developing harvest strategies for all its stocks.
31. High Seas Task Force, "Closing the net: Stopping illegal fishing on the high seas" (Governments of Australia, Canada, Chile, Namibia, New Zealand, and the United Kingdom, World Wildlife Fund, World Conservation Union, and the Earth Institute at Columbia University, 2006).
32. D. J. Agnew, D. Aldous, M. Lodge, P. Miyake, G. Parkes, "Allocation issues for WCPFC tuna resources" (paper WCPFC3-2006-15 submitted to the 3rd regular session of the Commission for the Conservation and Management of Highly Migratory Fish Stocks in the Western and Central Pacific Fisheries Commission, Apia, Samoa, 11 to 15 December 2006); available at www.wcpfc.int/wcpfc3/pdf/WCPFC3-2006-15 [Allocation].pdf.
33. M. Mooney-Seus, A. Rosenberg, "Best practices for high seas fisheries management: Lessons learned" (Chatham House Briefing Paper, Energy, Environment and Development Programme EEDP BP 07/03); available at www.chathamhouse.org.uk.
34. C. F. Caddy, D. J. Agnew, *Rev. Fish Biol. Fish.* **14**, 43 (2004).
35. K. W. Shertzer, M. H. Prager, *ICES J. Mar. Sci.* **64**, 149 (2007).
36. C. M. Roberts, J. P. Hawkins, F. R. Gell, *Philos. Trans. R. Soc. B* **360**, 123 (2005).
37. G. Stefansson, A. A. Rosenberg, *Philos. Trans. R. Soc. B* **360**, 133 (2005).
38. The number of stocks for which the stock status is undetermined depends largely on the number of additional species and stock complexes that are recognized by management authorities. For instance, New Zealand recognizes all its possible stocks, whereas the EU has not yet recognized individual stocks for some of the important bycatch species in EU waters, such as skates and rays. In the United States, 91% of 303 non-FSSI stocks are of undetermined status (see supporting online material).
39. D. S. Kirby, B. Molony, "An ecological risk assessment for species caught in WCPO longline and purse seine fisheries" (paper EB-WP-1 submitted to the 2nd regular session of the Scientific Committee of the Western and Central Pacific Fisheries Commission, Manila, Philippines, 7 to 18 August 2006); available at www.wcpfc.int/sc2/pdf/SC2_EB_WP1.pdf.
40. C. C. Mees, R. Arthur, in *Rebuilding Fisheries in an Uncertain Environment*, Proceedings of the 13th Biennial Conference of the International Institute of Fisheries Economics and Trade, 11 to 14 July 2006, Portsmouth, UK, A. L. Shriver, Ed. (International Institute of Fisheries Economics and Trade, Corvallis, OR, 2006), paper 236.

41. We thank numerous colleagues in the fisheries science and management world whose ideas have led to this paper. We dedicate this paper to Dr. Geoff Kirkwood, who tragically died in March 2006. If he had lived, he would have coauthored this paper and improved it considerably.

Supporting Online Material

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