Uncertainty, Resource Exploitation, and Conservation: Lessons from History

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There are currently many plans for sustainable use or sustainable development that are founded upon scientific information and consensus. Such ideas reflect ignorance of the history of resource exploitation and misunderstanding of the possibility of achieving scientific consensus concerning resources and the environment. Although there is considerable variation in detail, there is remarkable consistency in the history of resource exploitation: resources are inevitably overexploited, often to the point of collapse or extinction. We suggest that such consistency is due to the following common features: (i) Wealth or the prospect of wealth generates political and social power that is used to promote unlimited exploitation of resources. (ii) Scientific understanding and consensus is hampered by the lack of controls and replicates, so that each new problem involves learning about a new system. (iii) The complexity of the underlying biological and physical systems precludes a reductionist approach to management. Optimum levels of exploitation must be determined by trial and error. (iv) Large levels of natural variability mask the effects of overexploitation. Initial overexploitation is not detectable until it is severe and often irreversible.

In such circumstances, assigning causes to past events is problematical, future events cannot be predicted, and even well-meaning attempts to exploit responsibly may lead to disastrous consequences. Legislation concerning the environment often requires environmental or economic impact assessment before action is taken. Such impact assessment is supposed to be based upon scientific consensus. For the reasons given above, such consensus is seldom achieved, even after collapse of the resource.

For some years the concept of maximum sustained yield (MSY) guided efforts at fisheries management. There is now widespread agreement that this concept was unfortunate. Larkin (*1*) concluded that fisheries scientists have been unable to control the technique, distribution, and amount of fishing effort. The consequence has been the elimination of some substocks, such as herring, cod, ocean perch, salmon, and lake trout. He concluded that an MSY based upon the analysis of the historic statistics of a fishery is not attainable on a sustained basis. Support for Larkin's view is provided by a number of reviews of the history of fisheries (*2*). Few fisheries exhibit steady abundance (*3*).

It is more appropriate to think of resources as managing humans than the converse: the larger and the more immediate are prospects for gain, the greater the political power that is used to facilitate unlimited exploitation. The classic illustrations are gold rushes. Where large and immediate gains are in prospect, politicians and governments tend to ally themselves with special interest groups in order to facilitate the exploitation. Forests throughout the world have been destroyed by wasteful and short-sighted forestry practices. In many cases, governments eventually subsidize the export of forest products in order to delay the unemployment that results when local timber supplies run out or become uneconomic to harvest and process (*4*). These practices lead to rapid mining of old-growth forests; they imply that timber supplies must inevitably decrease in the future.

Harvesting of irregular or fluctuating resources is subject to a ratchet effect (*3*): during relatively stable periods, harvesting rates tend to stabilize at positions predicted by steady-state bioeconomic theory. Such levels are often excessive. Then a sequence of good years encourages additional investment in vessels or processing capacity. When conditions return to normal or below normal, the industry appeals to the government for help; often substantial investments and many jobs are at stake. The governmental response typically is direct or indirect subsidies. These may be thought of initially as temporary, but their effect is to encourage overharvesting. The ratchet effect is caused by the lack of inhibition on investments during good periods, but strong pressure not to disinvest during poor periods. The long-term outcome is a heavily subsidized industry that overharvests the resource.

The history of harvests of Pacific salmon provides an interesting contrast to the usual bleak picture. Pacific salmon harvests rose rapidly in the first part of this century as markets were developed and technology improved, but most stocks were eventually overexploited, and many were lost as a result of overharvesting, dams, and habitat loss. However, in the past 30 years more fish have been allowed to spawn and high seas interception has been reduced, allowing for better stock management. Oceanographic conditions appear to have been favorable: Alaska has produced record catches of salmon and British Columbia has had record returns of its most valuable species (*5*).

We propose that we shall never attain scientific consensus concerning the systems that are being exploited. There have been a number of spectacular failures to exploit resources sustainably, but to date there is no agreement about the causes of these failures. Radovitch (*6*) reviewed the case of the California sardine and pointed out that early in the history of exploitation scientists from the (then) California Division of Fish and Game issued warnings that the commercial exploitation of the fishery could not increase without limits and recommended that an annual sardine quota be established to keep the population from being overfished. This recommendation was opposed by the fishing industry, which was able to identify scientists who would state that it was virtually impossible to overfish a pelagic species. The debate persists today.

After the collapse of the Pacific sardine, the Peruvian anchoveta was targeted as a source of fish meal for cattle feed. The result was the most spectacular collapse in the history of fisheries exploitation: the yield decreased from a high of 10 million metric tons to near zero in a few years. The stock, the collapse, and the associated oceanographic events have been the subject of extensive study, both before and after the event. There remains no general agreement about the relative importance of El Niño events and continued exploitation as causes of collapse in this fishery (*7*).

The great difficulty in achieving consensus concerning past events and a fortiori in prediction of future events is that controlled and replicated experiments are impossible to perform in large-scale systems. Therefore there is ample scope for differing interpretations. There are great obstacles to any sort of experimental approach to management because experiments involve reduction in yield (at least for the short term) without any guarantee of increased yields in the future (*8*). Even in the case of Pacific salmon stocks that have been extensively monitored for many years, one cannot assert with any confidence that present levels of exploitation are anywhere near optimal because the requisite experiments would

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involve short-term losses for the industry (9). The impossibility of estimating the sustained yield without reducing fishing effort can be demonstrated from statistical arguments (*10*). These results suggest that sustainable exploitation cannot be achieved without first overexploiting the resource.

The difficulties that have been experienced in understanding and prediction in fisheries are compounded for the even larger scales involved in understanding and predicting phenomena of major concern, such as global warming and other possible atmospheric changes. Some of the time scales involved are so long that observational studies are unlikely to provide timely indications of required actions or the consequences of failing to take remedial measures.

Scientific certainty and consensus in itself would not prevent overexploitation and destruction of resources. Many practices continue even in cases where there is abundant scientific evidence that they are ultimately destructive. An outstanding example is the use of irrigation in arid lands. Approximately 3000 years ago in Sumer, the once highly productive wheat crop had to be replaced by barley because barley was more salt-resistant. The salty soil was the result of irrigation (*11*). E. W. Hilgard pointed out in 1899 that the consequences of planned irrigation in California would be similar (*12*). His warnings were not heeded (*13*). Thus 3000 years of experience and a good scientific understanding of the phenomena, their causes, and the appropriate prophylactic measures are not sufficient to prevent the misuse and consequent destruction of resources.

Some Principles of Effective Management

Our lack of understanding and inability to predict mandate a much more cautious approach to resource exploitation than is the norm. Here are some suggestions for management.

1) Include human motivation and responses as part of the system to be studied and managed. The shortsightedness and greed of humans underlie difficulties in management of resources, although the difficulties may manifest themselves as biological problems of the stock under exploitation (*2*).

2) Act before scientific consensus is achieved. We do not require any additional scientific studies before taking action to curb human activities that effect global warming, ozone depletion, pollution, and depletion of fossil fuels. Calls for additional research may be mere delaying tactics (*14*).

3) Rely on scientists to recognize problems, but not to remedy them. The judgment of scientists is often heavily influenced by their training in their respective disciplines, but the most important issues involving resources and the environment involve interactions whose understanding must involve many disciplines. Scientists and their judgments are subject to political pressure (*15*).

4) Distrust claims of sustainability. Because past resource exploitation has seldom been sustainable, any new plan that involves claims of sustainability should be suspect. One should inquire how the difficulties that have been encountered in past resource exploitation are to be overcome. The work of the Brundland Commission (*16*) suffers from continual references to sustainability that is to be achieved in an unspecified way. Recently some of the world's leading ecologists have claimed that the key to a sustainable biosphere is research on a long list of standard research topics in ecology (*17*). Such a claim that basic research will (in an unspecified way) lead to sustainable use of resources in the face of a growing human population may lead to a false complacency: instead of addressing the problems of population growth and excessive use of resources, we may avoid such difficult issues by spending money on basic ecological research.

5) Confront uncertainty. Once we free ourselves from the illusion that science or technology (if lavishly funded) can provide a solution to resource or conservation problems, appropriate action becomes possible. Effective policies are possible under conditions of uncertainty, but they must take uncertainty into account. There is a well-developed theory of decision-making under uncertainty (*18*). In the present context, theoretical niceties are not required. Most principles of decision-making under uncertainty are simply common sense. We must consider a variety of plausible hypotheses about the world; consider a variety of possible strategies; favor actions that are robust to uncertainties; hedge; favor actions that are informative; probe and experiment; monitor results; update assessments and modify policy accordingly; and favor actions that are reversible.

Political leaders at levels ranging from world summits to local communities base their policies upon a misguided view of the dynamics of resource exploitation. Scientists have been active in pointing out environmental degradation and consequent hazards to human life, and possibly to life as we know it on Earth. But by and large the scientific community has helped to perpetuate the illusion of sustainable development through scientific and technological progress. Resource problems are not really environmental problems: They are human problems that we have created at many times and in many places, under a variety of political, social, and economic systems (*19*).

REFERENCES AND NOTES

1. P. Larkin, *Trans. Am. Fish. Soc.* **106**, 1 (1977).
2. Pelagic stocks are described by A. Saville, Ed., *Rapports et Procès-Verbaux des Réunions* [*Cons. Int. Explor. Mer* 177 (1980)]. A general survey is given by W. F. Royce, *Fishery Development* (Academic Press, New York, 1987), and tropical fisheries are reviewed by D. Pauly, G. Silvestre, I. R. Smith, *Nat. Res. Model.* **3**, 307 (1989).
3. J. Caddy and J. Gulland, *Mar. Policy* **7**, 267 (1983).
4. R. Repetto and M. Gillis, Eds., *Public Policies and the Misuse of Forest Resources* (Cambridge Univ. Press, Cambridge, 1988).
5. R. C. Francis and T. H. Sibley, *Northwest Environ. J.* **7**, 295 (1991); S. R. Hare and R. C. Francis, in *International Symposium on Climate Change and Northern Fish Populations*, Conference in Victoria, Canada, 13 to 16 October 1992; in preparation.
6. J. Radovitch, in *Resource Management and Environmental Uncertainty. Lessons from Coastal Upwelling Fisheries*, M. R. Glantz and J. D. Thompson, Eds. (Wiley, New York, 1981).
7. R. Hilborn and C. J. Walters, *Quantitative Fisheries Stock Assessment* (Chapman & Hall, New York, 1992).
8. C. J. Walters and J. S. Collie, *Can. J. Fish. Aquat. Sci.* **45**, 1848 (1988).
9. C. J. Walters, in *Applied Population Biology*, S. K. Jain and L. W. Botsford, Eds. (Kluwer Academic, Norwell, MA, 1992).
10. R. Hilborn and J. Sibert, *Mar. Policy* **12**, 112 (1988); D. Ludwig, in *Springer Lecture Notes in Biomathematics*, vol. 100, S. Levin, Ed. (Springer-Verlag, New York, in press); R. Hilborn, *J. Fish. Res. Board Can.* **33**, 1 (1979); D. Ludwig and R. Hilborn, *Can. J. Fish. Aquat. Sci.* **40**, 559 (1983).
11. T. Jacobsen and R. M. Adams, *Science* **128**, 1251 (1958); M. de Vreede, *Deserts and Men* (Government Printing Office, The Hague, Netherlands, 1977).
12. E. W. Hilgard, *Univ. Calif. Coll. Agricult. Bull. 86* (1899).
13. W. R. Gardner, in *Arid Lands Today and Tomorrow*, Proceedings of an International Research and Development Conference, E. Whitehead, C. Hutchinson, B. Timmerman, R. Varady, Eds. (Westview Press, Boulder, CO, 1988), p. 167.
14. M. Havas, T. Hutchinson, G. Likens, *Environ. Sci. Technol.* **18**, 176A (1984); see comments, *ibid.* **19**, 646 (1985); W. B. Innes, *ibid.*, p. 646.
15. D. Cram, in *Resource Management and Environmental Uncertainty. Lessons from Coastal Upwelling Fisheries*, M. R. Glantz and J. D. Thompson, Eds. (Wiley, New York, 1981), p. 145; G. Sætersdahl, in *Rapports et Procès-Verbaux des Réunions*, A. Saville, Ed. [*Cons. Int. Explor. Mer* **177** (1980)]; D. W. Schindler, *Ecol. Appl.* **2**, 124 (1992); F. N. Clark and J. C. Marr, *Prog. Rep. Calif. Coop. Ocean Invest.* (July 1953); *ibid.* (March 1955); this was reported in (*6*).
16. World Commission on Environment and Development, *Our Common Future* (Oxford Univ. Press, New York, 1987).
17. Lubchenko *et al.*, *Ecology* **72**, 371 (1991).
18. H. Chernoff and L. E. Moses, *Elementary Decision Theory* (Wiley, New York, 1959; reprinted by Dover, New York, 1986); D. V. Lindley, *Making Decisions* (Wiley, New York, ed. 2, 1985); J. O. Berger, *Statistical Decision Theory and Bayesian Analysis* (Springer, New York, 1985).

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