PRECAUTIONARY MANAGEMENT OF MARINE FISHERIES: MOVING BEYOND BURDEN OF PROOF

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ABSTRACT

A more precautionary approach to marine fishery management is much needed, but a central issue is how decisions are made when, as is usual, uncertainties are large. Reversing the burden of proof (showing that a given fishing level is safe before allowing it) is a necessary but not sufficient condition for a precautionary approach. Several policy aspects of the burden of proof issue should be clarified: what the default decision will be; who bears the burden of demonstrating that a change from the default is justified; what metric is used to decide on a change; and what rate of incorrect changes from the default is tolerable. Fishery decision making would benefit from more specificity about management goals, preagreement on how data will be used in reaching decisions, and an explicit linking of fishing levels to the degree of certainty of fish stock condition. Finally, we argue that a truly precautionary approach requires a broader philosophical outlook than seeing the oceans as simply providing exploitable resources. Management should aim to maintain all marine species as functioning components of their ecosystems and to permit a proposed activity only if it can be demonstrated not to have an adverse effect.

Marine fishery management is changing (Sissenwine and Rosenberg, 1993; Restrepo et al., 1999; Weeks and Berkeley, 2000). The reasons are complex, because fishery management systems are complicated mixtures of biological, environmental, social, and economic issues. Sissenwine and Rosenberg (1993) summarize the basic problems necessitating the changes as uncontrolled participation (open access), uncertain scientific information, and risk-prone management decisions, which interact in a vicious cycle. Some (Ludwig et al., 1993) are more pessimistic than others (Rosenberg et al., 1993) about dealing with the problems, but agreement is broad that changes are needed in how management decisions are made in the face of uncertainty about stock condition and other factors. The central issue is captured by Gulland's pithy observation that the history of fisheries management is "interminable debate about the condition of fish until all doubt is removed" (quoted by Sissenwine and Rosenberg, 1993).

These problems require new structures and methods of fishery management, particularly a more 'precautionary approach' (Hanna, 1999; Weeks and Berkeley, 2000; Ludwig, this issue). A precautionary approach has many aspects, including research, management, and technology (FAO, 1996; Mace and Gabriel, 1999). The difficult part, as Ludwig (Ludwig et al., 1993; Ludwig, this issue) has described it and as the examples given by Rosenberg (this issue) show, is less in devising a precautionary management policy than in overcoming the political forces that oppose its implementation.

Burden of Proof and Precautionary Management

Whether a decision is made in a fishery-management council or a court of law, burden of proof is a fundamental issue. Where the burden of proof is placed determines the default—in other words, the decision that will be made unless data show it should not. When inference is based on hypothesis testing, the burden of proof determines, in effect, the null hypothesis that must be rejected before results can be accepted as statistically significant. Peterman (1990), Peterman and M'Gonigle (1992), and Taylor and Gerrodette (1993) pointed out, in the context of statistical power, how insufficient data in combination with the traditional burden of proof lead to nonprecautionary decisions and actions. In fishery management, the burden of proof is usually to show that proposed reductions in catch are needed—i.e., to show that current levels are causing some undesired effect such as overfishing. A precautionary approach would reverse this burden by making conservative fishing levels the default and maintaining those levels until higher levels are shown to be justified. The guidelines for responsible fisheries of the Food and Agriculture Organization of the United Nations call for such an approach in the case of new or developing fisheries (FAO, 1996). The 1996 amendments to the Magnuson-Stevens Fisheries Conservation and Management Act (MSFCMA) shift the burden of proof to a degree, in the sense that targets, such as optimum yield, should be set safely below limits, such as maximum sustainable yield (MSY), even when data are lacking (Restrepo et al., 1999). In general, however, consensus is lacking on what to do when information is inadequate to delineate the trade-offs between the goals we wish to achieve and the outcomes we wish to avoid (Weeks and Berkeley, 2000).

Another issue is who bears the burden of demonstrating that a given target level of fishing is not harmful. Typically, the burden of proof is on the fishery management agency to demonstrate harm before reductions in catch are justified. Dayton (1998) suggested that the burden of proof should be reversed. Because the living organisms in the oceans are public resources, fishers, either commercial fishers who profit from harvest of the resources or sport fishers who use them for recreation, should bear the burden of showing that their activities will not cause damage to the marine ecosystem. Costanza et al. (1998) include this idea among their principles for the sustainable governance of the oceans. A well-known model is the burden that pharmaceutical companies bear to show that new drugs are safe before they can be sold to the public. Well-defined protocols exist for extensive testing of new drugs, first on animals and later on humans in clinical trials. A related issue is who should pay for such studies. In the case of new drugs, the pharmaceutical companies pay for the studies, and the costs are ultimately passed on to those who purchase and use the drugs. In the case of fisheries, costs of studying and managing fish stocks are usually paid out of general tax revenues.

Furthermore, we must recognize that simply reversing the burden of proof does not guarantee a precautionary approach. A 'proof' has two parts: the metric on which a decision is based and the level (or standard) of proof that the metric must meet. To demonstrate that a certain level of fishing is not harmful to the marine ecosystem, one must first define what is meant by 'harm' (the metric). Is it causing the target fish stock to fall below a certain level? Is it failing to maintain the ecological relationships among several fish species? Is it threatening any species (including species other than fish) with extinction? Second, one must state explicitly the standard of proof that must be met. How certain do we wish to be that a certain fishing level will have no harmful effects? Obviously, if this standard is set too high, it would be impossible to demonstrate 'no harm' given the large uncertainties in making any predictions about marine ecosystems, and no fishing could ever occur. On the other hand, if the standard is set too low, management would not be precautionary, even if the burden of proof were reversed, because the probability that fishing would cause some undesirable effect would be too high. The choice of standard of proof inherent in the balancing of risks is the point at which a policy choice is most clearly made about how precautionary we wish to be.

These four questions—(1) what is the default decision, (2) who must demonstrate that change is needed, (3) what metric signals the need for change, and (4) what rate of error is tolerable—are classic policy issues. The choices made on these four issues determine, in large part, whether a precautionary approach will be implemented or not. If the issues are left undefined or vague, the process of making fishery-management decisions is likely to be inconsistent and controversial because different groups may reach different conclusions from the same data.

Making Decisions

"Fisheries management is primarily a decision process" (Hilborn et al., 1993). Science and policy play complementary roles in decision making: decisions are based on data (science) but require value judgments about how to use these data (policy). Reflecting this separation of roles, most management systems have a scientific (assessment) component and a policy (decision-making) component. Available data usually include biological data on the condition of the fish stock as well as social and economic data about the impacts of decisions on fishing communities. Management must often meet multiple objectives. For example, in the United States, "the determination of [optimum yield] is a decisional mechanism for resolving the Magnuson-Stevens Act's multiple purposes and policies, implementing [a fishery management plan's] objectives, and balancing the various interests that comprise the national welfare" [50 CFR 600.310(b)].

Specific Goals.—Laws like the Marine Mammal Protection Act (MMPA) and the MSFCMA state broad policy goals. For example, the MMPA declares that marine mammal populations "should not be permitted to diminish beyond the point at which they cease to be a significant functioning element in the ecosystem of which they are a part" (Sec. 1361 (2)). The MSFCMA declares that a purpose of the act is to "achieve and maintain, on a continuing basis, the optimum yield from each fishery" (Sec. 2 (b) (4)). These general goals guide managers in making decisions but, when applied to data, are too broad to allow reliable and consistent decisions. Absent more specific criteria, and in the face of the multiple objectives of the MSFCMA, there is ample room for differing interpretations of whether an "optimum" yield is being achieved or whether the allowed catch "to the extent practicable, minimize[s] adverse economic impacts on [fishing] communities."

The goals of the MSFCMA have been operationalized through the National Standards Guidelines (50 CFR 600, subpart D) and related workshops and documents (e.g., Rosenberg, 1993; Restrepo, 1999; Mace, 2000). Regional fishery-management councils, in cooperation with scientists, develop control rules that determine management actions on the basis of data such as stock status. Many control rules are possible, however, and the choice of a best control rule cannot be made until 'best' is defined. The next step is therefore for managers to define performance criteria for control rules, so that the operational characteristics of alternative control rules can be evaluated (National Research Council, 1998; Restrepo et al., 1998). A similar approach of specifying performance criteria for control rules, and testing them with extensive simulations, proved successful in developing a workable management scheme for whaling (Cooke, 1995).

Preagreement.—In any contentious situation, reaching agreement ahead of time on the rules of the game is highly desirable. Preagreement on control rules and status-determination criteria may be implicit in the National Standard Guidelines, but the technical guidance for achieving optimum yield (Restrepo et al., 1998: 15) explicitly says that a control rule is "a pre-agreed plan for adjusting management actions." To be sure, control rules attempt to meet diverse and sometimes conflicting management objectives, but this problem only emphasizes the need to agree beforehand on the plan for adjusting management actions. Restrepo et al. (1998) noted that preagreement ensures that management actions can be implemented without delay under rapidly changing conditions. Preagreement also ensures that all interests are committed to the decision once it is made. In the ideal case, the decision criteria are unambiguous and comprehensive, so that once data have been analyzed, the decision based on the data is uncontroversial. Achieving this situation would contribute greatly to resolving many conflicts over fishing effort and allocation. Anderson et al. (1999) describe how preagreement on data, analysis, and decision criteria contributed to resolving a conflict over the effect of logging on northern spotted owls.

Uncertainty and Margin of Safety.—Decisions are based on the predicted effects of different catch levels on fish stocks and fishing communities, but such predictions are inherently uncertain. A central problem for both fishery scientists and managers is therefore to deal with this uncertainty. The process of decision making should be explicit about how uncertainty will be included in a precautionary management system. While scientists recognize uncertainty, and indeed the evaluation of how 'good' estimates are forms an important part of stock assessments, the management structure is such that the uncertainties are not always clearly expressed and communicated to the decision makers (Hilborn et al., 1993). Risk analyses (Brown and Patil, 1986; Francis, 1992; Restrepo et al., 1992), Bayesian stock assessments (Thompson, 1992), and the use of decision tables (MacCall, 1999) make uncertainties more explicit. Decision theory provides a formal way for uncertainty to be incorporated into decisions (Hilborn and Peterman, 1996; Hilborn, 1997), but without more explicit guidelines, it is not clear how these quantitative estimates of uncertainty, even when they are provided, would be used consistently by decision makers. For example, the National Standards Guidelines state that fishing targets should be set safely below fishing limits. But how much is 'safely' below? In the absence of a clear standard or regulatory guidance, various interpretations are certain to arise about whether a given fishing target meets this criterion. Clarification of such policy issues is needed before managers can deal with uncertainty in a consistent and coherent way.

A basic feature of any precautionary or risk-averse approach to natural resource management is that the less certain we are about the effects of an action, the more cautious we should be (Holt and Talbot, 1978; Mangel et al., 1996). The National Standards Guidelines clearly say so: "Criteria used to set target catch levels should be explicitly risk averse, so that greater uncertainty regarding the status or productive capacity of a stock or stock complex corresponds to greater caution in setting target catch levels" [50 CFR 600.310(f)(5)(iii)]. The FAO Code of Conduct for Responsible Fisheries notes that the standard of proof in management decisions should be commensurate with the potential risk to the resource (FAO, 1996).

The margin of safety should therefore increase as uncertainty increases. For current U.S. fishery management, precautionary buffers (the difference between targets and limits) should therefore be a positive function of uncertainty. A simple way to achieve this goal is to tie the decision quantity (e.g., target effort or catch level) to a confidence or credibility interval. When data are sparse, uncertainty about relative effort and biomass levels is high, and the precautionary buffer is large (Fig. 1A). With better data, uncertainty is less and higher fishing targets are justified (Fig. 1B). Making catch level depen-

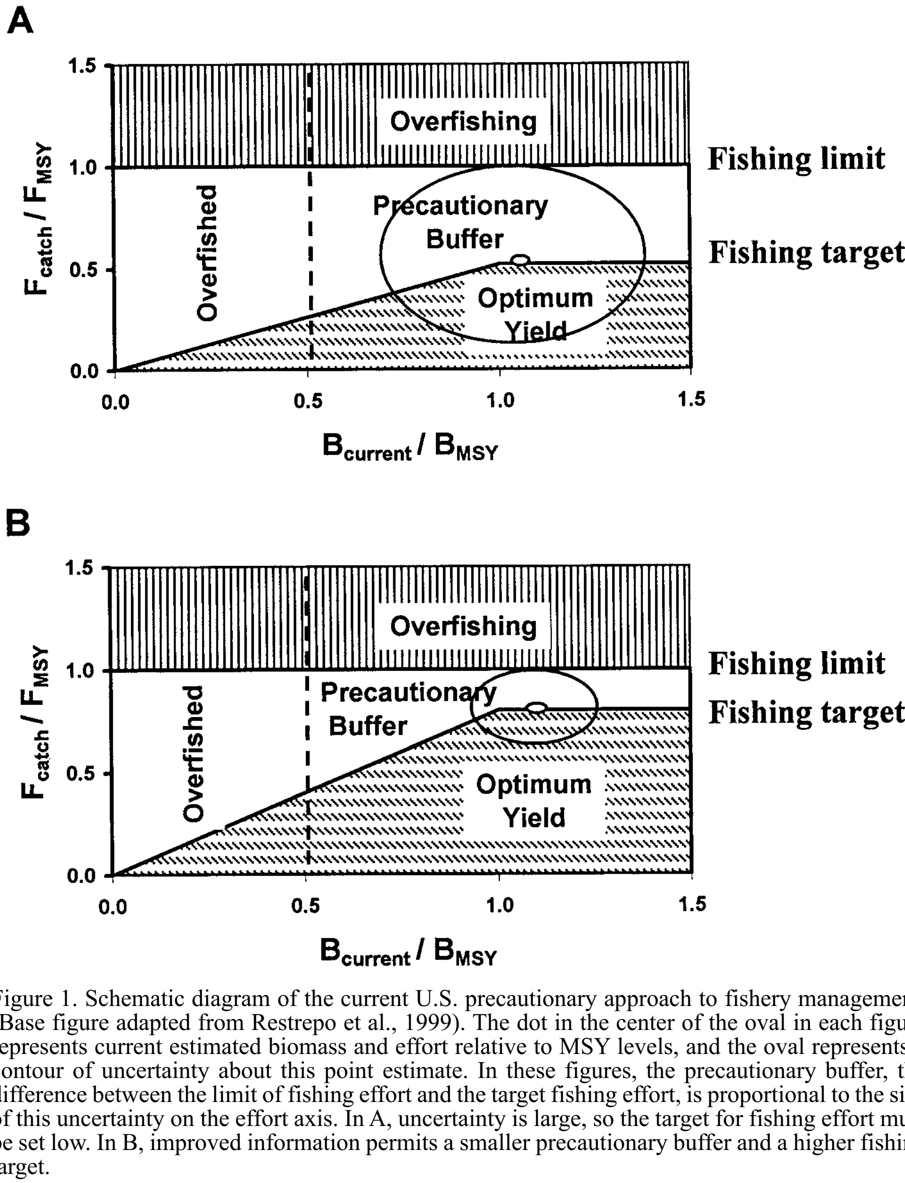

Figure 1. Schematic diagram of the current U.S. precautionary approach to fishery management. (Base figure adapted from Restrepo et al., 1999). The dot in the center of the oval in each figure represents current estimated biomass and effort relative to MSY levels, and the oval represents a contour of uncertainty about this point estimate. In these figures, the precautionary buffer, the difference between the limit of fishing effort and the target fishing effort, is proportional to the size of this uncertainty on the effort axis. In A, uncertainty is large, so the target for fishing effort must be set low. In B, improved information permits a smaller precautionary buffer and a higher fishing target.

dent on the quality of data has the additional advantage of providing incentives for better data, because information then has value for fishers, managers, and scientists. It also directs money and effort where they are most needed to increase knowledge.

Allowable Marine Mammal By-catch.—Determining allowable levels of by-catch for marine mammals has raised many of the same issues as the current movement toward precautionary fishery management, and the successes and failures of the mammal experience may be instructive. By-catch in fisheries is the main threat to most marine mammals in the United States. Determining whether by-catch is 'too high' may be a contentious issue, because actions to reduce by-catch can have economic effects on fishers. After the passage of the MMPA in 1972, U.S. management of marine mammals was based on maintaining marine mammal stocks above "optimum sustainable population size," operationally defined as being above the maximum net productivity level (MNPL) (Gerrodette and DeMaster, 1990; Taylor and DeMaster, 1993). In terms of fishery management, MNPL was a biological reference point against which to measure 'good' and 'bad' marine mammal stock condition, much as $B_{current} < B_{MSY}$ is a 'bad' fish stock condition we seek to avoid. Although the MNPL was conceptually clear, estimating whether a particular marine mammal population was above or below it proved difficult even when extensive data were available (Ragen, 1995). For most stocks, the required data were not available (Gerrodette and DeMaster, 1990).

In addition to requiring data difficult to obtain, this decision criterion did not address the uncertainty involved in any estimate of stock condition (Taylor et al., 2000). The question "How certain do we have to be that a marine mammal population is below MNPL before some management action is called for?" was never answered. The implicit assumption was that populations were above MNPL, and therefore in good condition, until shown otherwise. Given this burden of proof, the paucity of information about marine mammals in the wild, and no explicit standard of proof, it was extremely difficult to demonstrate that any marine mammal population was below MNPL. The difficulties became evident within a few years after passage of the MMPA, when dolphins killed in the eastern tropical Pacific tuna fishery were not declared to be below MNPL despite the massive kill going on (Gosliner, 1999). In the 22 yrs after passage of the MMPA (i.e., prior to the 1994 amendments), the status of only a handful of the 153 marine mammal stocks in U.S. waters had been determined (Read and Wade, 2000).

In response to this failure, management of marine mammal by-catch evolved to a more practical system based on keeping by-catch below certain conservative levels that depended on measurable quantities. Explicit policy choices were made about tolerable error rates—about the probability, for example, of failing to keep a population above MNPL. Given these choices, the parameters of the control rule were tuned with simulations to achieve the management goals (Wade, 1998). In fisheries terms, the new system sets allowable marine mammal by-catch at a target level safely below a limit, where 'safely' has been defined by policy choices. Allowable by-catch is calculated with an easily understood formula based on a simple production model. The rules about making the decision have been agreed on ahead of time, so little disagreement arises about status under this new system, and the determination of whether by-catch is too high is driven primarily by the quantity and quality of data available. The scheme is risk-averse in that the less known about the size of a marine mammal population, the smaller the allowed by-catch. This risk-averse property results from setting the allowed by-catch proportional to the lower end of a 60% log-normal confidence interval on estimated population size (Fig. 2). A 60% confidence interval was chosen because simulations showed that, in terms of policy goals and likely biases in data, a higher quantile provided more protection for the marine mammal stock than was necessary and penalized fishermen (Wade, 1998). In addition, when data are scarce, the scheme provides incentives for more data. More data mean better estimates, better estimates mean higher allowed by-catch, and higher allowed by-catch means more fishing (Fig. 2).

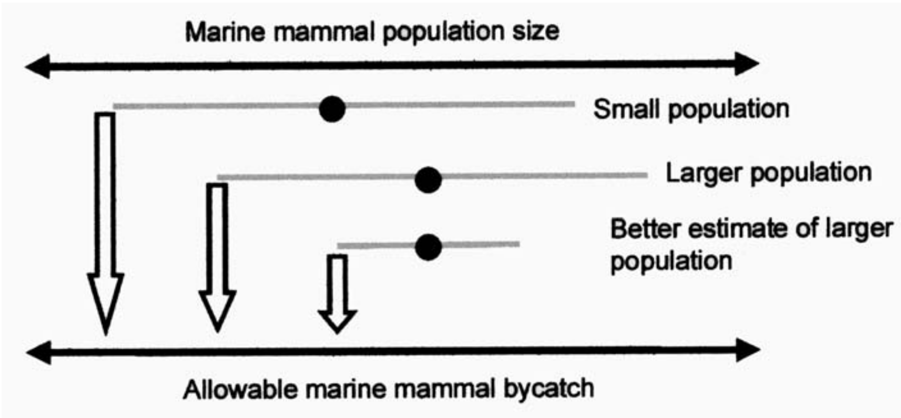

Figure 2. Schematic diagram illustrating a precautionary aspect of setting allowable marine mammal by-catch. The large dots represent point estimates of marine mammal abundance, and the gray bars confidence intervals on those estimates. Allowable by-catch is proportional to the lower end of the confidence interval. Thus, allowable marine mammal by-catch increases with increasing population size but decreases with increasing uncertainty about population size (i.e., with larger confidence intervals).

The Scope of Precaution

A precautionary approach to fishery management has widespread support and growing application, but what are we being precautionary about? At present, the emphasis is on the condition of the fishery's target fish stock and on the people who make a living catching the fish. By exercising precaution in management decisions, we seek to maintain the stock at a productive and sustainable level; healthy fish stocks will, in turn, maintain healthy fishing communities.

These are certainly desirable goals, but a fishery-management system with such a narrow scope fails at being truly precautionary. Fishing has many collateral ecological effects. For example, most fishery-management systems do not take account of incidental mortality, habitat destruction, or ecosystem impacts such as altered interspecific interactions that affect the population dynamics of the target fish populations themselves. On a more general level, fishery management does not take into account the total biodiversity of ocean ecosystems.

Utilitarian Reasons for Broader Scope.—The process of fishing has many effects beyond the direct removal of the target species. For utilitarian reasons alone, a truly risk-averse management system should take account of these other effects on both target and nontarget species. Fishing has many broad environmental impacts (Dayton et al., 1995), but for the purposes of this short discussion, they can be grouped as by-catch, habitat alteration, and food-web effects.

By-catch is a serious fishery-management issue. By-catch of the target species includes catches of unusable, unmarketable, or illegal sizes of fish, as well as catch of the target species in the gear of other fisheries. This additional mortality of the target species must be taken into account for proper analysis of the stock's population dynamics. By-catch becomes a conservation issue when a fishery kills nontarget species in large numbers. For species with low reproductive rates, such as seabirds, marine turtles, marine mammals, and some fishes, especially sharks, by-catch even in low numbers can have strong population effects. Species with small population size and/or limited range are particularly vulnerable (see, e.g., D'Agrosa et al., 2000; Dawson et al., 2001).

Habitat alteration usually occurs when fishing gear interacts with the sea floor. Trawls and dredges scrape the sea floor, causing direct physical changes to the sea bottom and its associated biota as well as indirect effects such as suspension of sediment in the water. Animals and plants that live on or in the sea floor may be killed by the direct or indirect effects. Habitat alteration can affect a fish stock's population dynamics drastically by changing the food supply, protection from predators, and nursery habitat for young fish. Another type of habitat alteration is fishing debris that may entangle, entrap, or be ingested by various organisms (Laist, 1997). The effects of habitat alteration on the target species may be poorly understood, but the effects are not therefore unimportant. To ignore the habitat alteration and assume that it is unimportant to the dynamics of the fishery is hardly risk-averse. On the contrary, to ignore such effects would be a risk-prone strategy.

Marine ecosystems include all the physical and biological factors important to particular species. Species are linked together in a complex web of interactions including competition for resources, predator-prey interactions, commensal and parasitic relationships, structural habitats, and a host of indirect interactions. Some of these linkages are stronger than others, but in general, when the abundance of one component of the system is altered, many compensatory changes occur. A fishery typically removes a large portion of the standing biomass of a fish stock and alters the age, size, and genetic structure of the population. Even if a fishery causes no by-catch of other species and no habitat effects, these changes in population abundance and structure will affect the marine ecosystem. The abundance of predators and prey of the target species will change. Competitors may fill in some of the vacant 'niche' of the target species, or the whole ecosystem may shift to a different state (Simenstad et al., 1978; Fogarty and Murawski, 1998). The decreasing trophic levels taken by marine fisheries may indicate that ecosystem-level changes are occurring (Pauly et al., 1998). Ecosystem management has been widely acknowledged for a long time to be a desirable goal, but it remains a substantial challenge to incorporate ecosystem considerations into management advice, for both scientific and political reasons (Cortner and Moote, 1999). The present discussion of precautionary management, including appropriate targets and limits, does not enlighten us with regard to meaningful biological thresholds of the type that characterize entire marine ecosystems.

A Broader Philosophical Scope.—Fishery management, like other natural-resource management, developed under utilitarian goals of maximizing catch of the target species for human benefit. The growing list of serious environmental problems has prompted calls for new principles of management for both terrestrial and marine ecosystems, based on a broader conservation ethic (Mangel et al., 1996; Costanza et al., 1998; Safina, 1998), but it takes time for such new ways of thinking to become accepted by the public at large and to be implemented by fishermen, fisheries scientists, and managers. Part of the current precautionary approach to fishery management is an increased emphasis on the consideration of nontarget species. For example, optimum yield is defined in the MSFCMA to mean, among other things, the number of fish that provides "the greatest overall benefit to the Nation . . . taking into account the protection of marine ecosystems" (Sec. 3 (28) (A)), but the underlying utilitarian ethic is still clear. The *Federal Register* notice proposing the revised National Standards Guidelines describes the emphasis on the protection of marine ecosystems as “the new provisions concerning the identification and description of essential fish habitat” (62 FR 41910, 4 August 1997). In other words, whole marine ecosystems should be protected, because they represent essential habitat for fish. The implicit assumption is that other species in the oceans have value only insofar as they contribute to sustainable fishing.

On the other hand, managers of public natural resources have the responsibility to protect future environmental options for all of society. These options include the privilege of enjoying natural systems for esthetic, educational, and scientific purposes as well as harvesting them for profit. Leopold (1949) wrote of the need for a land ethic; we need an ocean ethic (Safina, 1998). We need to see the oceans as providing more than resources that can be destructively exploited, to adopt an ocean ethic that implies that all marine species and ecosystems have great value and therefore merit precautionary protection. The United States has a long history of implementing this philosophy, having established and protected many national parks and wilderness areas, and marine protected areas are a natural extension of this idea. Within the U.S., the Endangered Species Act is the clearest expression of an ecological ethos in which all species and their habitats are protected; it commits us to protecting all species, not just those with economic value.

Are we really ready to embrace a precautionary approach to fisheries extractions from the oceans? Are we ready to restrict a fishery because it damages deep-water corals that hardly anyone ever sees? We should not underestimate how fundamental a change in management philosophy this is. In the U.S. at least, it has proven difficult to take a precautionary approach with regard to marine mammals, which have charisma and their own protection act, and even with regard to endangered marine mammals, which have the additional protection of the Endangered Species Act. The current controversies over possible fishery restrictions designed to protect the Steller sea lion, Hawaiian monk seal, and sea turtles indicate that we as a society do not seem ready to accept the kind of direct short-term economic losses that a precautionary approach might require.

Perhaps it is too much to ask that a fishery-management act, even a precautionary one, protect algae and starfish (although the MSFCMA does inclusively define ‘fish’ as all “marine animal and plant life other than marine mammals and birds”!). Perhaps a new law is needed for a wider precautionary approach to all marine species. Whatever the mechanism, we argue that society should embrace a holistic precautionary approach to management of marine systems, in which the default position is that species should be maintained as functioning components of their ecosystems and in which a proposed activity is permitted only if it can be demonstrated not to affect adversely the integrated processes of the ecosystem.

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