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PRINCIPLES FOR THE CONSERVATION OF WILD LIVING RESOURCES[1,2,3]

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Abstract. We describe broadly applicable principles for the conservation of wild living resources and mechanisms for their implementation. These principles were engendered from three starting points. First, a set of principles for the conservation of wild living resources (Holt and Talbot 1978) required reexamination and updating. Second, those principles lacked mechanisms for implementation and consequently were not as effective as they might have been. Third, all conservation problems have scientific, economic, and social aspects, and although the mix may vary from problem to problem, all three aspects must be included in problem solving. We illustrate the derivation of, and amplify the meaning of, the principles, and discuss mechanisms for their implementation.

The principles are:

Principle I. Maintenance of healthy populations of wild living resources in perpetuity is inconsistent with unlimited growth of human consumption of and demand for those resources.

Principle II. The goal of conservation should be to secure present and future options by maintaining biological diversity at genetic, species, population, and ecosystem levels; as a general rule neither the resource nor other components of the ecosystem should be perturbed beyond natural boundaries of variation.

Principle III. Assessment of the possible ecological and sociological effects of resource use should precede both proposed use and proposed restriction or expansion of ongoing use of a resource.

Principle IV. Regulation of the use of living resources must be based on understanding the structure and dynamics of the ecosystem of which the resource is a part and must take into account the ecological and sociological influences that directly and indirectly affect resource use.

Principle V. The full range of knowledge and skills from the natural and social sciences must be brought to bear on conservation problems.

Principle VI. Effective conservation requires understanding and taking account of the motives, interests, and values of all users and stakeholders, but not by simply averaging their positions.

Principle VII. Effective conservation requires communication that is interactive, reciprocal, and continuous.

Mechanisms for implementation of the principles are discussed.

Key words: biodiversity; communication; conservation principles; consumption; ecological economics; habitat; human consumption; human population growth; institutions; resource depletion; resource use; sustainability; wild living resources.

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[2] This paper is the result of a workshop organized and sponsored by the Marine Mammal Commission and held 6–9 March 1994 at Airlie House, Virginia, USA. Each author prepared an informal discussion paper for the workshop and participated in drafting one or more principles. The authors' professional affiliations can be found on p. 354. Full addresses of other authors are available from the Marine Mammal Commission, 1825 Connecticut Avenue, N.W., Room 512, Washington, D.C. 20009, USA.

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Introduction

The natural world is in crisis. Wild living resources are depleted at increasing rates, the ecosystems upon which they depend are generally perturbed, and consumption of resources by a growing human population generally increases. Because the human condition directly depends upon a sound and functioning natural environment, there is great jeopardy from global ecological decline. The challenge to humanity is to fundamentally change the way it interacts with the ecological systems that directly and indirectly support it. Failure to do so could result in the collapse of existing socio-economic systems and irreversible declines in the quality of life in both developed and developing countries. The time has arrived to develop a different working relationship between people and natural resources.

Holt and Talbot (1978) described a set of principles for the conservation of wild living resources. These were developed through a series of workshops held in 1974 and 1975. However, partly because that work did not include an explicit set of mechanisms for implementation, those principles do not appear to have been effectively used or widely adopted. Consequently, the Marine Mammal Commission sponsored a series of consultations (Appendix I) with scientists and resource managers throughout the world from 1992 to 1994 to obtain global perspectives on wild-living-resource conservation. The Marine Mammal Commission also sponsored a workshop in March 1994 to: (1) determine why the 1978 principles have not been employed more widely or effectively; (2) develop more effective guiding principles for the conservation of wild living resources; and (3) describe mechanisms for implementation of those principles.

In this paper we review, amend, and expand on the 1978 principles. Special emphasis is placed on implementation of the principles in management and conservation schemes, because the noblest intentions are meaningless if they are not adopted as actual, functioning policy. The best possible relationship between humans and nature safeguards the viability of all biota and the ecosystems of which they are a part and on which they depend, while allowing human benefit (for present and future generations) through various uses. Conservation thus includes the consumptive and nonconsumptive use of resources (management) and the preservation of critical resources so that future options can be kept open and so that normal ecological structure and function may continue. The challenge is to determine the appropriate balance between the health of resources and ecosystems and the health and quality of human life. This balance requires understanding the broad range of issues that is the focus of this paper.

The 1978 Principles

The principles for the conservation of wild living resources published in 1978 (Holt and Talbot 1978:14–15) were:

The consequences of resource utilization and the implementation of principles of resource conservation are the responsibility of the parties having jurisdiction over the resource or, in the absence of clear jurisdiction, with those having jurisdiction over the users of the resource. The privilege of utilizing a resource carries with it the obligation to adhere to the following general principles:

1. The ecosystem should be maintained in a desirable state such that
   a. consumptive and non-consumptive values could be maximized on a continuing basis,
   b. present and future options are ensured, and,
   c. the risk of irreversible change or long-term adverse effects as a result of use is minimized.
2. Management decisions should include a safety factor to allow for the fact that knowledge is limited and institutions are imperfect.
3. Measures to conserve a wild living resource should be formulated and applied so as to avoid wasteful use of other resources.
4. Survey or monitoring, analysis, and assessment should precede planned use and accompany actual use of wild living resources. The results should be made available promptly for critical public review.

In the early 1970s most resource managers behaved as if it were possible to manage the use of living resources in a relatively sustainable and predictable way; the only question was how to achieve that sustainable yield. The philosophy was that each resource had a maximum or optimum sustainable yield level and that the measurement and calculation of the appropriate levels were feasible if enough natural history and demography of the resource were known. Thus, resource conservation was regarded primarily as a biological problem, and the key to maximum sustained use was information about the species or stocks and their ecosystems, as well as analysis of biological data to develop appropriate management regimes.

The perspective is far different today (Appendices I and II). First, there are few unexploited living resources in the world and many resources are heavily overexploited. Second, while there are different views about "sustainable use" of renewable resources, even those who argue that it is possible admit that our performance over the recent past has been poor. For example, at least 42% of the fishery stocks in the United States are over-exploited (Anonymous 1991, Rosenberg et al. 1993). Third, the belief of the 1970s—that for management purposes one could assume that ecosystems were stable, closed, and internally regulated and behaved in a deterministic manner—has been replaced by recognition that ecosystems are open, in a constant state of flux, usually without long-term stability, and affected by many factors originating outside of the system. Fourth, there is increased recognition of the role of social and economic factors in determining whether a management regime will be successfully implemented, regardless of how sound it is scientifically. Indeed, successes in protecting or restoring populations of terrestrial wildlife have involved key elements of the biological and ecological knowledge of the species and its ecosystem, coupled to various social processes, including public support (Robinson and Bolen 1989).

It is now clearly understood that conservation problems have scientific, economic, and social components, although the particular mix will vary according to circumstances. It is imperative to account for all of these aspects if the conservation effort is to be successful (Cole-King 1993). Thus, effective conservation almost always requires understanding specific motivations of the users of the resources. Because humans cannot effectively control ecosystems, and often cause great damage in trying to do so, human action and the social processes that affect it must be addressed in order to conserve wild living resources.

The Principles and Mechanisms

We have arrived at seven principles, grown out of the 1978 principles, taking into account intervening developments in relevant fields. Most importantly, we include potential mechanisms for implementing the principles. These principles are guidelines for attaining a persistent relationship between humanity and wild living resources. The mechanisms are not protocols for how to do what needs to be done, but a check list of key questions that must be addressed.

Principle I. Maintenance of healthy populations of wild living resources in perpetuity is inconsistent with unlimited growth of human consumption of and demand for those resources

There is no question that infinite growth is impossible in a finite system. The human population cannot continually expand without eventually overwhelming its base of natural resources. Thus, the underlying and most critical aspect of any effort to conserve wild living resources is to slow down and eventually decrease human per capita demand for resources. Without that step, continued population growth and resource use must lead to disaster. It is almost certain that the only practicable way to reduced human per capita resource demand is to stabilize and then decrease the human population.

As obvious as this may appear, this principle must be explicitly stated because of the current focus on "sustainability." The Brundtland Commission Report *Our common future* (World Commission on Environment and Development 1987) and its successor, *Caring for the earth: a strategy for sustainable living* (IUCN/UNEP/WWF 1991) appear to be unaware of (or to simply ignore) the relationship between human population growth and environmental deterioration. When humans use resources in ways that allow natural processes to replace what is used, sustainability is achieved. That is, living off of nature's "interest," rather than its "capital," is key to any concepts of sustainability and good resource management. This approach, combined with a stable or decreasing human demand on resources, is a prerequisite to effective conservation of wild living resources. Even then, direct sustainable management of target species may have unsustainable indirect effects.

The following mechanisms will help implement this principle:

1) *Recognize that the total impact of humans on wild living resources is the product of human population size, per capita consumption, the impact on the resource of the technologies applied, and incidental taking and habitat degradation caused by other human activities. Take appropriate actions that recognize these characteristics.*

Ehrlich and Holdren (1974) called this "$I = PAT$," where I is total environmental impact, P is population size, A is level of affluence (a measure of consumption of goods), and T is a measure of technological sophistication and its impact. This relationship indicates the overall potential for environmental impact of a society. Although in many developing nations the human population continues to grow at a rapid pace, the overall impact may be ameliorated by lower affluence and lesser technological impact. Indeed, some levels and kinds of industrial development may actually reduce pressure on natural resources. Conversely, more industrialized, developed nations may have impacts out of proportion to their smaller population sizes or growth rates because of great individual consumption and use of more advanced technologies (Ehrlich and Ehrlich 1990).

With no other constraints, in a finite world with finite resources, the sheer numerical increase in the human population must eventually threaten the security of resources and human life. But long before that population size is reached, increasing technological capabilities along with inappropriate institutional arrangements and goals may lead to catastrophic declines in wild living resources. Furthermore, the problem goes beyond resource use. Recent sociological work has revealed a connection between large-scale, human-induced environmental pressures and threats to national and international security such as revolution and rebellion (e.g., Goldstone 1991, Homer-Dixon 1994).

Some groups believe that the only way to conserve wild living resources is to prevent access by people to the species and their ecosystems. Perhaps more to the point, aside from general agreement with the notion that there is a human population problem, managers of wild living resources have often not seen the human population issue as something directly part of their profession and activities. In the past, the concepts and practices of wild-living-resource conservation proceeded as if the human population problem can be ignored in day-to-day planning and actions. This is no longer feasible (Meffe et al. 1993, Brouha 1994, Pulliam and Haddad 1994, Hodges 1995), and population growth must be recognized as a critical conservation problem, both in training and actions of resource managers.

2) *Recognize that if urban areas and other intensely used land areas were more efficient, safer, and more pleasant, there would be a greater chance of conserving wild living resources.*

By the end of this century the urban population will increase to >75% of the population in developed countries and ≈40% in the developing countries. In 1950 only a few urban areas had populations of $>4 \times 10^6$ people, but by 2000 it is likely there will be 57 cities in this category. In 1950 the largest urban area in the world (New York and Northeastern New Jersey) had 12.3×10^6 people. In 1990 the five largest urban areas each exceeded this, and the largest, Tokyo-Yokohama, numbered $>20 \times 10^6$ people (United Nations 1989). When urban environments are unpleasant, residents are more likely to attempt to leave cities, either permanently to create new urban areas (urban sprawl), or temporarily, for vacations, putting pressure on living resources and their habitats. If cities were more pleasant and livable, the chances for conserving wild, living resources would likely improve. Similarly, if the use of wild lands for vacations is not too consumptive, then those lands become more valuable to society and may be more likely to be conserved. As a consequence, those interested in conservation have a vested interest in improving urban environments as well as reducing the rate of human population growth.

As urbanization increases, the local (and sometimes global) effects on the environment increase. Because cities are commonly located near rivers and the coast, urban sprawl often covers the good agricultural land that occurs on river flood plains and coastal wetlands, which are important habitats for domesticated and wild plants and animals. We must again find ways to make cities livable, with pleasing features to protect health and improve well-being, with fewer effluents polluting the air and water, or exported as solid waste to more remote areas. Finally, improving the livability of cities must be done in a manner that does not place undue burden on resources elsewhere.

Principle II. The goal of conservation should be to secure present and future options by maintaining biological diversity at genetic, species, population, and ecosystem levels; as a general rule neither the resource nor other components of the ecosystem should be perturbed beyond natural boundaries of variation

Living resources and their ecosystems have an evolutionary history that shaped current ecosystem structure (Fowler and MacMahon 1982). Modern human use of these systems has been conducted for only centuries (or millennia) at most. To be effective, management must work within the constraints of natural law: fundamental physical laws and biological dynamics constrain human institutions and desires, not the reverse (Meffe 1993). In this principle we recognize that resource use should be guided by the goals of maintaining the fullest possible range of options for future generations and of minimizing changes in the structure and dynamics of populations and ecosystems that cannot be fully reversed within one human generation. Even then, this condition cannot guarantee persistence if the ecosystem experiences a sequence of catastrophic, but natural, shocks.

As noted many years ago, all forms of life modify their environments (White 1967). Civilization as we know it could not have evolved without transforming ecosystems, and even some of the earliest civilizations caused considerable environmental degradation (Hong et al. 1994) and mass extinctions (Steadman 1995). However, the capabilities of modern technology dictate that we be explicitly aware of their effects on natural systems, and of the potential reduction or loss of biodiversity at all levels (Hughes and Noss 1992).

The following mechanisms will help implement this principle:

1) *Manage total impact on ecosystems and work to preserve essential features of the ecosystem.*

The most effective management is of human impact. Most habitats have already been exposed to long-term human impact, and human activities will generally be conducted in ecosystems that have a litany of problems, which may already include extreme stress from pollutants—and/or that the ecosystem is too small or too highly fragmented, that important species have been lost, or that invasive species are present. Consequently, managing impacts will be difficult under most circumstances. The extensive linkages and the amorphous nature of the boundaries between habitats make it important to develop as integrated a regional plan as possible so as to include the management of human activities as well as management of components of the ecosystem. In addition, it is imperative that management agencies work together and that managers learn to work with multiple agencies.

By identifying things that are critical to a given ecosystem (such as nutrient dynamics, life history parameters of critical species, need for migratory pathways, and/or major external threats and opportunities) one can design a management plan that accommodates a wide variety of human uses while preserving that which is most critical for the continued viability of the ecosystem. But a distinction must be made between managing a living resource with an ecosystem approach and managing an ecosystem. An individual species or population as a resource may be managed while taking into account its interactions with other elements of its ecosystem. This is resource management with an ecosystem approach. Managing ecosystems, on the other hand, means managing the entire system by integration of ecological, economic, and social factors to control the biological and physical systems (Wood 1994). Currently, this is difficult to do as an informed activity (Slocombe 1993) because the concepts are ill defined, great uncertainty exists about most ecosystems, and methods are just developing. Although realistic methods for comprehensive ecosystem management are not fully developed, basic rules and principles are emerging (Grumbine 1994, Meffe and Carroll 1994) and resource managers must think in multi-species and functional terms.

2) *Identify areas, species, and processes that are particularly important to the maintenance of an ecosystem, and make special efforts to protect them.*

Contributions of local populations to total population persistence are not uniform across space or time. Some locations act as sources of individuals, who then migrate to other areas, while other locations act as sinks, which cannot maintain themselves indefinitely (Pulliam 1988). Such systems of metapopulations are collections of populations connected by periodic or regular movement of individuals, and typically exist across habitat patches of heterogeneous quality. Source populations are important reservoirs of colonists for other sites. Even if they play extremely important ecological roles, sink populations must decline over time unless they are supported by immigration from source areas. Thus, source areas are disproportionately valuable. In fact, protection of sink areas without protection of their sources is likely to result in extinction.

Process-oriented conservation, where efforts are made to protect functional attributes of a system, is critical. Because of constraints imposed by limited resources and time, some allocation of effort should go to targeting critical processes. Process-oriented conservation (such as maintaining burn regimes in fire-dependent ecosystems, or reintroducing predators where they have been removed) involves an important shift in the paradigm of resource managers from targeted stocks to targeted functions. This change is imperative, especially for marine fisheries systems and other cases of regular harvest from wild stocks.

3) *Manage in ways that do not further fragment natural areas.*

Habitat fragmentation has two components: (1) loss of total habitat area and (2) distribution of remaining habitat into smaller, more discontinuous parcels. The consequences of fragmentation range from loss of gene flow, through interruption of source-sink dynamics, to loss of species (Harris 1984, Saunders et al. 1991). Recent theoretical work (Tilman et al. 1994) shows that even moderate habitat destruction can lead to delayed but certain extinction of the dominant species in the remaining habitat. Because habitat fragmentation is so widespread, its avoidance should be a major emphasis in resource management plans.

4) *Maintain or mimic patterns of natural processes, including disturbances, at scales appropriate to the natural system.*

The proper definition of temporal or spatial scale is generally based on the scale of appropriate natural disturbances (e.g., fires, landslides, storms, floods), pertinent biological processes (e.g., herbivory, disease, foraging, reproduction), and dispersal characteristics and capabilities of the component populations. Populations evolve in the milieu of natural disturbances and natural variation, and their resilience is determined by adaptation to these evolutionary patterns (Holling 1973, Wiens and Milne 1989). Management should be cognizant of such evolutionary adaptations, especially with regard to dependency on disturbances (Starfield et al. 1993). Long-term field work is needed to differentiate between baseline variation and rare catastrophes (Trivelpiece et al. 1990, Young and Isbell 1994).

The life history patterns of species illustrate the importance of understanding and structuring exploitation to mimic natural processes. The survival of long-lived species with low growth rates, delayed maturation, and small litter size depends upon high adult survivorship, and (usually) multiple reproductive episodes (Congdon et al. 1993). Such species include primates, elephants, cetaceans, sea turtles, sharks, many freshwater turtles, lake trout, and many large birds. These species have evolved a life history strategy that requires females to have many years of reproductive opportunity in order to have a high probability of reproductive success. By increasing the mortality rate or being size selective and removing the larger, older individuals, the average lifespan will decrease and hence there is a greater chance that the population will not be able to persist in the presence of naturally occurring environmental fluctuations. Compensatory efforts such as hatchery rearing or headstart programs, designed to increase recruitment rates, address only the symptoms, not the underlying causes of declines (Frazier 1992, Meffe 1992). In contrast, short-lived species with high reproductive rates are typically heavily influenced by environmental fluctuations as well as harvest. These species can decline and disappear before the problem is recognized, so that special monitoring effects are needed.

5) *Avoid disruption of food webs, especially removal of top or basal species.*

The food web is one of the structuring agents of natural communities (Pimm 1991). Recent work (Naeem et al. 1994) demonstrated that communities with reduced diversity in the food web performed (e.g., in terms of community respiration, decomposition, nutrient retention, plant productivity, and water retention) more poorly than those with higher diversity. Consequently, disruption of food webs through addition or elimination of species can be a destabilizing force.

Predators can affect the abundance and types of prey populations, and prey availability in turn influences the abundance and types of predators. Indirect or cascading influences may also be important, although they are rarely investigated. For example, endemic Hawaiian plants of the genus *Hibiscadelphus* became extinct or nearly extinct because of the extinction of several species of the Hawaiian honeycreepers, which were their pollinators (Diamond 1989). Similarly, a predator may feed upon a prey species that is an important herbivore on one or more plant species. Removal of the predator allows populations of the herbivore to expand and reduce or eliminate some or all of the plant populations (Pimm 1991). Such indirect effects are felt throughout the food web. Introduction of species alien to a system frequently results in disruption of food webs. This is especially critical when the alien species is an effective predator on native species or if introduction releases it from its native predators, parasites, or pathogens. It then has the opportunity to greatly alter the new system.

6) *Avoid significant genetic alteration of populations.*

Although we still lack definite rules that relate genetic variation to persistence of populations (Lande and Barrowclough 1987, Burgmann et al. 1993), it is likely that reduction of genetic variation and/or genetic alteration of populations will generally reduce the ability of organisms to adapt to changing environmental conditions. Law et al. (1993) document the genetic impacts of commercial fisheries. Such changes are critically important when they lead to over-harvesting in the application of conventional resource management. Also, because existing genetic variation provides an important mechanism for organisms to respond to natural and human-induced change, there is great virtue—if not necessity—in maintaining that variation.

7) *Recognize that biological processes are often nonlinear, are subject to critical thresholds and synergisms, and that these must be identified, understood, and incorporated into management programs.*

Nonlinearity and threshold effects are pervasive in biological systems. For example, a pathogen may suddenly become a plague once it reaches a threshold density; reproduction may not occur until population densities pass a threshold high enough for individuals to find each other; and populations of a given species may only be viable above some critical threshold of patch (habitat) size, below which a refuge is ineffective. Such effects are all non-linear—a small change in a variable may have a large effect—and can occur suddenly and unexpectedly (May and Oster 1976). If not anticipated, they can seriously affect management programs. Similarly, synergisms—interactive effects of different agents in which the total cooperative effect is positive and greater than the sum of the individual effects—can have far-reaching influences on conservation (Young 1994). For example, seals in the North Sea may have been weakened by pollution, which allowed their decimation in 1988 by viral disease (Harwood and Hall 1990).

The implications of nonlinearity and thresholds are that increases in harvest or other interventions should occur incrementally and take into account that lags may occur before effects are manifested. In addition, adequate monitoring, which can provide the factual basis for rapid changes in policy should evidence suggest that a nonlinear effect is acting or a threshold crossed, is essential.

Principle III. Assessment of the possible ecological and sociological effects of resource use should precede both proposed use and proposed restriction or expansion of ongoing use of a resource

The concept of a "right to use the resource" must be changed to the "privilege to use the resource." Even in the case of privately owned resources, owners must recognize the potential effects of resource use far from their own location and be held accountable for adverse effects.

The intention of this principle is to make clear that demonstrating that resource use will not be damaging is the responsibility of those who want to use it. It is based on the recognition (regarding proposed use) that behaving in a risk-averse manner may avoid losses or unacceptable risks, achieve equity among user groups and between generations, and (regarding proposed restriction) avoid overcapitalization and drastic decreases in harvest rates. If parties cannot agree on what "assessment" means, then use must be delayed or curtailed to protect the resource and to minimize the tendency to use delaying tactics while continuing to use the resource.

Implementing this principle for activities already underway or planned requires monitoring to verify that use does not or will not have unacceptable effects. In many, if not most, cases it will not be possible to accurately predict the effects of various types and levels of resource use on the targeted resource or other ecosystem components. Because it is generally prohibitively costly, if not impossible, to assess and monitor every system variable that could be affected by resource use, the essential task is to identify a representative subset of species and ecosystem variables and processes that are most likely to change in detectable ways in response to resource use. Managers must design and execute monitoring programs that will enable possible adverse effects to be detected before they reach harmful levels. Like management programs, monitoring programs should be periodically reviewed and modified as necessary, to better meet the desired goals.

The following mechanisms will help implement this principle:

1) *Identify uncertainties and assumptions regarding natural history, size, and productivity of the resource, and its role in the ecosystem.*

Traditional use of natural resources was based on the beliefs that (1) owners of resources have the right to do whatever they want with the resources; (2) if a resource is not owned by someone, it can be used by anyone; and (3) use cannot be restricted unless some individual or entity with legal standing objects and can show that it, its property, or the public welfare is being affected adversely by the activity. These may have been reasonable tenets when resource use was small in comparison to resource availability and the resource users were part of the local community and routinely interacted with community members. Problems arose and became more serious, however, as human populations, expectations of life style, per capita consumption rates, and technology for recovering, transporting, and marketing resources grew and as users are increasingly not part of the local community (e.g., foreign fishing fleets or international forest companies). Consequently, one often observes unregulated use of common property resources and management systems that require the public or the responsible regulatory agency to show that resource use is having some type of unacceptable effect, before use can be limited or regulated. These characteristics almost inevitably lead to: (1) competition for access to resources; (2) development of resource-use industries faster than development of knowledge concerning the resource and its ecosystem; (3) over-capitalization of the industry; (4) over-exploitation and depletion of the resource; (5) damage, waste, or loss of other components of the ecosystem; (6) loss of capital investment and related socio-economic impacts because the long-term yield is far below the exploitation capacity that has developed; and (7) managing the industry to protect capital investment and minimize short-term socio-economic impacts, rather than to maintain the resource at a level providing long-term benefits.

To prevent or minimize the risk of such outcomes, it is imperative to identify the possible biological, ecological, and socio-economic effects of resource use and incorporate them in the planning or exploratory phase of resource development. This must occur before there is significant capital investment and before the scope or scale of use begins to approach potentially harmful levels. The assessments should clearly identify and indicate the possible consequences of uncertainties and assumptions concerning the natural history, size, and productivity of the resource and its role in the ecosystem. To be useful, assessment of proposed activities must usually come from ecosystems that are perturbed from their natural state; otherwise the range of observations may be too narrow to identify functional relationships among components. For example, in order to predict the effect of certain harvesting strategies, it may be necessary to harvest. In order to minimize risk, this should be done cautiously and in conjunction with adequate monitoring and a management structure that will respond quickly to problems.

2) *Identify major ecological and socio-economic uncertainties and assumptions.*

Use of wild living resources often proceeds without knowledge or consideration of possible effects on the target resource or other components of the ecosystem. As a result, many resources have been and are being severely over-exploited. In addition, utilization of a resource often results in waste of other resources (e.g., discard of non-target species in commercial fisheries, Alverson et al. 1994), and damage or destruction of the ecosystem.

Various aspects of this problem have been recognized and addressed, at least partially. Many cities have zoning laws that prohibit owners from using their land in ways that would directly or indirectly reduce the value of adjacent properties. Similarly, many local, state, and national governments have enacted laws requiring that the possible effects of development activities be identified and considered before the activity is authorized. Legislation such as the U.S. Marine Mammal Protection Act of 1972 prohibits consumptive use of wild living resources until it can be shown that, taking into account the health and stability of the ecosystem, the proposed use, by itself and in conjunction with other activities, would not disadvantage the species or stock. Provisions for assessing and avoiding possible adverse environmental impacts appear in a number of international agreements (Wallace 1994). Such procedures should be used to ensure that uncertainties and assumptions concerning possible ecological and socio-economic effects are considered before there is irreversible biological change or significant capital investment.

3) *Analyze how the resource and other ecosystem components might be affected by proposed use if the assumptions are not valid.*

Assessments of the possible effects of resource use should clearly identify (1) the data and assumptions upon which they are based, (2) uncertainties concerning the reliability of the data or validity of the assumptions, (3) possible consequences of the planned action(s) if the assumptions or assessments are not valid, (4) possible measures that could be taken to reduce the risk of long-term or irreversible effects, and (5) the nature and extent of the research and monitoring programs that would be required to reduce uncertainties to acceptable levels and to verify that the proposed actions do not have unacceptable effects. In general, management plans should incorporate a range of the possible states of the ecosystem and the consequences if the basis of the management plan is wrong, and they should provide contingencies that can be implemented in case of failure.

It is generally appropriate to assume that, until proven otherwise, use of wild living resources will have unacceptable effects on both the target resource and on other components of the ecosystem. This changes the working hypothesis from "use of the resource will have no effect" to "use of the resource will have serious effects." It also changes the burden of proof from those responsible for conserving the resource to those who want to use the resource. An example of this mechanism is provided by the Commission for and the Scientific Committee for the Conservation of Antarctic Marine Living Resources. In 1991 the Commission adopted a conservation measure requiring that members intending to develop new fisheries in the Convention Area notify the Commission at least 3 mo in advance of the Commission's next regular meeting and provide information on the proposed fishery, including an assessment of its possible impacts on dependent and associated species. In 1993 the Commission extended the provisions of this conservation measure regarding new fisheries to developing fisheries for which there is insufficient information to estimate potential yield and potential impacts on dependent and related species. The conservation measure requires that a data-collection plan be formulated and updated annually by the Scientific Committee. It also requires that each member active in the fishery or intending to authorize a vessel to enter the fishery must annually prepare and submit a research and fishery operations plan to the Commission, for review by the Scientific Committee and the Commission. In addition, the measure requires that each vessel participating in an exploratory fishery carry a scientific observer to ensure that data are collected in accordance with the data-collection plan.

4) *When available information is insufficient to make informed judgments, authorize activities contingent upon development and approval of an information-acquisition plan that will ensure that the level of resource use does not increase faster than does knowledge of the size and productivity of the resource and its relationships with other ecosystem components.*

Resource use can be structured to provide information about the resource. Effective monitoring and experimental management help minimize the chance of long-term adverse effects on the resource and related components of the ecosystem. Management strategies should also be designed to minimize impacts on people and communities whose livelihood depends directly upon current use of a particular resource. In general, greater weight should be afforded to short-term socioeconomic considerations when developing management strategies for existing resource-use industries (e.g., commercial fisheries and lumber industries) than for designing strategies for new or developing industries for which there is little or no existing socio-economic dependency. In the latter case, greater weight should be afforded to long-term biological considerations. However, all management strategies should include safety factors, commensurate with the degree of uncertainty (e.g., Frederick and Peterman 1995), to ensure that authorized activities will not seriously reduce future options.

The plan for acquiring data and information during resource use should clearly identify the data and underlying assumptions, the possible consequences of any uncertainties concerning the validity of the assessment(s), and the additional baseline studies, deliberate perturbation experiments, or monitoring programs proposed to be carried out to resolve the uncertainties. The plan should take into account the response times of the target and associated species. Finally, the observers associated with data collection must be independent of the organization and preferably the country that is financing the program.

5) *Require those most likely to benefit directly from use of a wild living resource to pay the costs of (a) developing the information-acquisition plan, (b) implementing the information-acquisition plan and (c) managing use of the resource. Only when the general public receives notable benefit is it appropriate for public monies to pay the costs.*

Users should be expected to pay for the acquisition of information as part of the cost of business. Thus, an appropriate share of the cost of the programs for research, assessment, monitoring, and management should be borne by the primary beneficiaries of those programs. In some cases, this may be the general public; in others, it may be particular individuals, corporations, or communities. When the general public is a beneficiary, it is appropriate for part of the costs to be covered by public monies, rather than solely by individuals. For example, women with ovarian cancer are beneficiaries of taxol from yew trees and consequently some public monies are appropriate for the development of taxol chemotherapy.

6) *Be prepared for unexpected events because the natural world is highly complex and stochastic, and human understanding of it always contains uncertainty.*

We lack a comprehensive, predictive understanding of the impacts of human disruption on ecological systems. Because not all effects of various events can be predicted or anticipated, we must acknowledge that unexpected events will occur, and we should be prepared to act when such events arise.

If more were known about a particular ecosystem, the ability to make accurate predictions about the response of that system to perturbation would increase. However, the inherent complexity of ecosystems will preclude ever gaining complete predictive knowledge of any system. Therefore, it must be recognized that uncertainty is a fundamental part of working with ecosystems. Before policy makers and the public at large can embrace, understand, and accept uncertainty, scientists themselves must do so. Scientists must replace ecological certainty with honest assessments of uncertainty, and avoid presenting "facts" that have weak empirical bases, are subject to multiple interpretations, or have been contradicted outright.

Furthermore, rather than focusing mainly on Type I errors by reporting *P* values from statistical tests, scientists should also calculate the statistical power of their conclusions (Peterman 1990, Peterman and M'Gonigle 1992), or use Bayesian statistics (Howson and Urbach 1993) to calculate different degrees of belief in alternative hypotheses, or use resampling methods to describe distributions of outcomes and associated confidence levels (Crowley 1992).

It is appropriate to use uncertainty to advantage rather than view it as something to be minimized. Almost any prediction or measurement regarding a natural system will contain variation and thus will have upper and lower bounds of confidence. This should be explicitly recognized and internalized into management prescriptions rather than ignored. Uncertainty should be incorporated into management programs in the context of the goals of the program, rather than dismissed as ignorance or noise, or used as an excuse to postpone management because not enough is yet known about the system. Long-term persistence of the resource has to receive the benefit of the doubt whenever uncertainty exists: uncertainty is a warning to exploit cautiously.

Principle IV. Regulation of the use of living resources must be based on understanding the structure and dynamics of the ecosystem of which the resource is a part and must take into account the ecological and sociological influences that directly and indirectly affect resource use

Although they are linked, ecological and economic systems are governed by different regulatory mechanisms and are based on fundamentally different currencies. Ecological systems typically function under internal and external constraints: prey species are checked by predator species; nutrient availability is a function of decay processes; herbivory is limited by anti-herbivore toxins. It is difficult for a single component to dominate an ecological system unless other components are fundamentally altered. Furthermore, the important biological properties are understood through a hierarchy of scales of analysis. At a local level, predators may check the growth of herbivores by occasionally eliminating local populations, but at the scale of the metapopulation, herbivores and their predators persist through immigration and re-colonization.

Most economic systems, on the other hand, are based on continual growth and expansion, involve generally abstract currencies, are regulated largely by supply and demand, and are often managed as though they were free of constraints from resource availability or waste disposal. Because of this lack of apparent constraints, a major resource-conservation problem is that resource use is driven largely by economic considerations, and often there is little constraint or feedback until the resource is overexploited. Economic growth, however well-intentioned, is not environmental policy (Arrow et al. 1995).

Effective living-resource management must be based first on understanding of the structure and dynamics of the natural system and of the constraints presented by that system and by natural laws, and then provide feedback to regulate economic systems within those constraints. Because the finite limits to resource use are based on natural, not human, law, and since exceeding those limits will eventually have catastrophic effects on both the ecological and the economic systems, they must be identified clearly.

Managers should take account of the impact of decisions about resource use on the market. In addition, managers must consider those ecological functions that do not have market value, but that have value to human society and that serve to maintain ecosystem integrity and function; ecosystem functions derive value from their role in satisfying human wants and needs and desires to leave ecosystems "pristine" (Ehrlich and Mooney 1983).

The following mechanisms will help implement this principle:

1) *Allocate the use of wild living resources on the basis of the ecological capabilities of the species involved and their assessed value to society.*

The use of a wild living resource must be compatible with the best available assessment of its capabilities to withstand that use. For example, heavy harvest of adults of a long-lived, slowly maturing, slowly reproducing species such as sea turtles or various rhinoceros species is incompatible with their persistence and cannot be allowed. Similarly, extensive logging of old-growth forests removes that age group from the landscape, eliminating its availability to species dependent upon it, and thus is incongruent with maintaining ecosystem and species diversity.

Allocating resources on the basis of their assessed value to society ensures that it will not be possible to change things in such a way as to make any one person better off without making someone else worse off. The estimation of such value is difficult but not impossible (Knetsch 1990, Coker and Richards 1992) and the unwillingness to make estimates underlies many resource disputes.

The values that living resources have to society incorporate all possible uses, including their existence value as components of an intact ecosystem. Thus the value of ecological resources includes their utilitarian value in direct production or consumption and their indirect value as components of ecosystems from which society derives a range of benefits: their amenity value, their aesthetic, scientific, and information value, and the value they have in preserving options to future generations and in enabling members of the present generation to preserve a "way of life" that is valued. The true economic value of living resources must include all of these, and is generally much greater than the immediate market or financial value of the resources. Thus, a broad range of ecosystem attributes needs to valued, ideally in an empirical and comprehensive manner, and one in which tradeoffs can be assessed (Knetsch 1990).

2) *Provide incentives to the users of living resources that correspond to the value those resources have to society. Ensure that these incentives promote conservation, and constrain all privilege of access to guarantee this.*

Developing positive incentives for conservation by resource users is essential, and effort is needed in this direction. In addition, those who derive benefit from the use of resources should be confronted with the true cost of their actions. It is analogous to the "polluter pays principle," but generalizes to cover all uses of living resources, and recognizes that the users and uses of resources may be very diverse. Users of living resources should be faced with the cost of those activities, even if they are responding to demands generated in the marketplace.

3) *Ensure that institutions and property rights are consistent with conservation, including questions of tenure and access.*

Property rights and security of tenure, which are social institutions associated with the use of wild living resources, are of primary importance to the incentives facing individual users. The lack of well-defined property rights ("open access"), and the uncertainty of continued access are among the strongest disincentives to conservation. We do not advocate any particular regime of property rights, nor any particular set of institutions. But property rights and institutions should be constructed that, so far as is possible, achieve (1) internalization of costs that are now external to and ignored by markets for resources, (2) regulation of access to common property resources so that the resources will persist, and (3) security of tenure for the users of living resources, as long as they use the resources within socially acceptable constraints.

User property rights come with associated user societal responsibilities and conservation constraints that cannot be ignored. Users should pay for the right of access to public resources, to help assure responsible treatment of the resource, and to help fund conservation.

Under some circumstances, property rights and security of tenure may influence individuals to act in a conservative manner because it is advantageous for them to do so. (There are cases in which rights and tenure have lead to degradation of the resource. The best known example is the way in which farmers have failed to preserve the productive capacity of their soils; Pimentel et al. [1995].) However, property rights and security of tenure are not sufficient. We still need a management structure that incorporates a multitude of values, accounts for ecosystem interactions and uncertainties, and establishes a conservative value system to protect the common resource.

4) *Protect the welfare of future generations by ensuring that the value of biotic and abiotic resources does not decrease over time.*

Exploitation in an ecological–economic system is fair to future generations if benefits do not decline over time and other components of the system are not adversely affected. This requires that the value of the assets of the ecosystem, including existence value, do not decrease. Three conclusions follow. First, conservation of the value of biotic and abiotic resources is essentially the same as conservation of the opportunities open to society. Second, trade-offs in the allocation of resources are possible and it may be possible to substitute some human-made capital for some ecological resources. Because species vary in their roles in the ecosystem, the loss of (or changes in) some are of greater consequence than in others. Essentially non-commensurable and poorly defined notions of relative productivity or relative importance can no longer be used. In a world of scarce resources, it is unhelpful to proceed from the premise that all resources are equally valuable. As unpleasant as this reality is, it must be faced or decisions will be abrogated, with the untenable result that economic interests will be given priority over biological reality and constraints. Third, there are limits to the substitutability between human-made capital and ecological resources, and whenever these limits might be approached we must act to preserve the ecological resources.

Although the practice of discounting involves ethical judgments about the responsibility that the present generation bears for future generations (Clark 1990), it will not generally be appropriate to address the problem of intergenerational equity via the discount rate. An ethically neutral discount rate exists, but in practice it may not be possible to estimate this rate and it is also not possible to enjoin private users of resources to associate with this rate. When economic activities have the potential to cause irreversible environmental damage that permanently reduces the welfare of future generations, priorities of the present generation must be placed behind those of future generations.

5) *Recognize the possible consequences of uncertainty and act accordingly.*

There are many different sources of uncertainty in ecological and economic systems. They include (1) uncertainty due to lack of information concerning the natural history, demography, and dynamics of the resource; (2) uncertainty concerning possible second-order effects due to lack of information concerning numerical and functional relationships among related species and populations; (3) uncertainty due to unpredictable, stochastic, or evolutionary change in either population or ecosystem parameters; and (4) uncertainty caused by basing decisions on best estimates when variance is large.

Given the pervasive uncertainty about ecological and economic dynamics, and the limits on our ability to control the joint ecological–economic system, management decisions should include wide safety margins to minimize the risks of irreversible change or long-term adverse effects. The existence of uncertainty should be addressed directly in the strategy for conserving living resources. Uncertainty should not be a cause for inaction, and biological uncertainty should not be allowed as an excuse to permit other factors to dominate decision making. More particularly, it should not be possible for a group of users of ecological resources to conduct what are, in effect, experiments on the behavior of ecosystems on which all society depends, unless an informed society accepts and is adequately insured against the consequences. In addition, management should enable the system to be probed in order to learn about it, and should adapt with changes in the available information.

6) *Promote adaptive management.*

Resource management should be adaptive, not prescriptive. Consequently, managers must be willing and able to amend management policies and practices as often and as quickly as necessary, and this must include a willingness to abandon management paradigms and to admit mistakes when evidence so dictates. The management process must always be accountable to the full range of stakeholders, and should be continually appraised according to biological, economic, and social targets. Since an important part of management is a strategy for learning about the systems concerned, management policy and programs should be designed in part to help acquire information needed to determine the size and productivity of the resource and its functional relationships with other components of the ecosystem. Management programs also should include predetermined responses to observe declines or other changes that signal unexpected and unacceptable responses to resource use. Managerial procedures must allow change in the face of new information, and provide economic incentives that encourage users to extract and to share information.

Principle V. The full range of knowledge and skills from the natural and social sciences must be brought to bear on conservation problems

Although biology must remain central for the conservation of living resources, other disciplines are important and input from them can be crucial. In particular, a critical step toward achieving successful conservation is to incorporate knowledge from the social sciences, including evaluation of information from those engaged in using resources, residents in or visitors to natural areas, and those otherwise familiar with resources. "The full range" in this principle refers not only to the variety of relevant disciplines, but also to the full depth of each.

The following mechanisms will help implement this principle:

1) *Invoke the full range of relevant disciplines at the earliest stage possible.*

The breadth of relevant knowledge and skills should be involved in the preparation of legislation and in formulating and implementing policy, including prior assessment of the issues, decision making, resolving conflicts, and monitoring and evaluating the execution of policy. This will often require breaking down long-standing and rigid institutional, professional, and personal barriers.

Effective linkages among scientific, economic, and social disciplines—and between all of these and executive authorities at all levels—are hindered by the absence of a common currency of "language." The same words (e.g., "conservation") are commonly applied by practitioners of different professions to distinctly different concepts. As far as practicable, a common language must evolve to facilitate discourse about practical conservation. It is unrealistic, however, to expect that the numerous professions and disciplines will keep in step. It is therefore essential that concepts are explicitly and clearly defined, that mutual understanding between the professions be enhanced, and that, as far as practicable, a unique meaning be ascribed to each term in discourse between the "expert" groups and the authorities.

2) *Recognize that science is only one part of living-resource conservation and is limited to investigating and objectively describing certain kinds of phenomena and processes.*

Science provides basic knowledge about the world and offers ways to gain additional knowledge and insight. What science can and cannot do needs to be clearly communicated to the public and decision makers. For example, science can be used to set the boundaries of activities consistent with conservation goals, including the uncertainty of those boundaries, but science cannot dictate where in the envelope society should operate. Similarly, science, by itself, is not capable of making judgments about esthetics or ethics. Science can tell us about the likely biological outcome of a decision or action, but not which, of all outcomes, we should value more highly. Scientists are value-laden in a host of ways, some of which may be "invisible" both to the scientists and to the public; thus, care must be taken to avoid mixing the values of scientists with the knowledge of scientists. Trust and credibility can only be maintained and enhanced (or, in some cases, reestablished) if this is done. For science to be relevant, it must be germane to the contemporary issues of decision making. For science to become more policy relevant, scientists must know how policy processes work, how to participate effectively in them (Clark 1993, Meffe and Viederman 1995), and how to differentiate between science and policy (factual knowledge and value judgments). This may necessitate a change in the way that science is done (Huenneke 1995, Underwood 1995).

The ongoing debate concerning global warming illustrates the point. Available information is insufficient to demonstrate beyond reasonable doubt that average temperatures are increasing worldwide. Similarly, available information is insufficient to determine precisely to what extent various human actions are either causing or contributing to global warming or what the eventual ecological and socio-economic consequences will be. Some scientists interpret the available information differently and, based on their interpretations, advocate different actions. Some do not differentiate clearly between known facts and uncertainties. As a result, neither the general public nor decision makers have a clear understanding of what is and is not known or the possible alternative courses of actions and their biological and socio-economic consequences.

This does not mean that scientists should not make value judgments or advocate particular policies or programs based on their judgments. Rather, scientists must take extreme care to differentiate between scientific fact and value judgment, so that both the public and the policy makers are aware of the facts, the uncertainties, and the possible consequences of alternative actions.

3) *Require comprehensive consultations because virtually all conservation issues have biological, economic, and social implications; ignoring any of these may lead to conflicts that will impair effective conservation.*

Consultations should be used to ensure that all stakeholders are aware of the options and their possible consequences. Such consultations are also desirable at the stage of establishing the conservation criteria themselves. Since practitioners of the various professions are commonly among the stakeholders of the resource in question, both directly as users and indirectly as paid consultants or research-grant recipients, the arrangements for consultations should recognize this.

There are examples of traditional uses that have not degraded the local ecosystem (Posey 1993) and it is important to learn from those indigenous cultures that have used resources in relatively non-destructive ways. Thus, relevant indigenous expertise should be sought, evaluated, and, where appropriate, incorporated into conservation policy.

Principle VI. Effective conservation requires understanding and taking account of the motives, interests, and values of all users and stakeholders, but not by simply averaging their positions

A consistent shortcoming of wild-living-resource policy has been the failure to understand and systematically incorporate the basic motives of all users and stakeholders (Kellert 1984) and the ways that human–environment interactions are reflected in the social and cultural discourse (Palsson 1991). Values (aesthetic, ethical, ecological) that vary among stakeholders can lead to divisive conflict, particularly when policy makers fail to take into account the primary motivations of major participants. Some stakeholders may be willing to accept a great range of risks to the resource, while others may be unwilling to accept any risk. Furthermore, what is considered unacceptable risk will vary in time and will depend upon available alternatives. The most effective means for satisfactorily resolving such conflict is by ensuring full participation of all relevant stakeholders in the decision-making process and conducting systematic assessments of all living-resource values.

Human groups have three foci that are fundamental in understanding and developing policies for conservation (Kellert and Clark 1991). The cultural focus considers the basic assumptions regarding the values and motives for using wild living resources. The socio-structural focus emphasizes community authority, power, and property relations associated with the allocation and use of resources. The institutional-regulatory focus stresses the character of formal organizations charged with the responsibility for giving expression to and implementing policies. Historical failures in recognizing the importance of these foci are legion, and have resulted in major conservation deficiencies and misallocation of biotic, financial, and other human resources (Gunderson 1985, Vidal 1993).

The following mechanisms will help implement this principle:

1) *Whenever possible, create incentives by delegating property rights to the "lowest" relevant community or societal level consistent with the scale of the resource involved.*

Increased tenancy and property rights for wild living resources among local and community stakeholders can enhance incentives for their conservation (Berkes 1985, Bromley 1991), even in cases where such resources are part of the "commons" (Monbiot 1994). Giving management responsibility to local stakeholders, particularly at the community level, fosters accountability and increases motivation for conservation, particularly if a close connection exists between conservation actions and the benefits of those actions. In many cases, there will be a direct local payoff to conservation through activities such as wildlife viewing; this strategy is being used in Uganda to conserve gorillas (Nowak 1995). In other cases, however, the wildlife themselves will never have direct economic value and the challenge is to ensure that those who can least afford it are not forced to pay for the conservation activity (Eltringham 1994). For example, the cost of the conservation of giant pandas in China includes new reserves, moving timber companies and their workers, and providing financial incentives to locals to resettle (O'Brien et al. 1994). The Chinese government agreed to cover ≈15% of the cost, with the remainder secured from outside sources. The continued existence of pandas should be of interest and value to the world community, so that a worldwide campaign for support would be a reasonable part of the solution.

Delegation of responsibility to the local community can also diminish resentment toward government officials, who are often viewed as having little stake in the preservation of traditional community institutions or resources. Increasing local control can additionally foster participation of stakeholders in the formulation of conservation policy. The difficulty with this approach is that individuals and corporations involved in use of the resource may not be tied to a specific spatial location, and after local resources are overutilized, new sources will be sought. For example, in the successive overexploitation of whale stocks in the North Atlantic, whaling fleets moved from the Barents Sea to Iceland to the Arctic as locally developed controls were instituted (Hjort 1933, Smith 1994).

Local control has a number of advantages when the users and the effects of use are local. These include (1) maximizing incentives for local management; (2) increasing the security of tenure and property rights among communities and stakeholders involved; and (3) forcing the development of co-management institutions among local and national authorities and relevant stakeholders. Regional, national, or international control will be required if the resource or effects of its use transcend the smaller political boundaries.

2) *Develop conflict-resolution mechanisms to minimize strife over resources among competing stakeholders.*

Almost all conservation problems will involve many different constituencies. For example, conservation of tropical rain forests involves the historical forest dwellers, the local farmers living in isolation, inhabitants of small villages (which may be long established or recently developed), the rural/urban population living in large villages or cities adjacent to forests, high-level government employees and decision makers who live in large cities removed from the forest, groups (such as timber or mining concerns) with special interests in the forest, judges and legislators who determine the laws and enforcement of those laws concerning the forest, and foreign groups with conservation or commodity interest in the forest. In the marine environment, a similar diversity of stakeholders exists, sometimes at the "micro" level. For example, some individuals use mobile harvest gear, which can damage or destroy the fixed gear used by other stakeholders.

Three main paradigms describing resource use are the "conservation paradigm," with the objective of conservation and maintenance of the resource; the "rationalization paradigm," with the objective of economic performance and productivity; and the "social paradigm," with the objective of community welfare and social equity (Charles 1992). It is natural that users operating within different paradigms may come into conflict, for which different resolutions are possible (Charles 1992).

Thus, giving authority to the local communities can foster competition and conflict among varying constituents involved in or affected by policies and their implementation. Such an enhanced democratic process may result in an increasingly volatile policy-making environment. In the long run this may result in more effective and equitable living-resource allocation, but is likely to require an enhanced capability for resolving conflicts among competing constituencies, for example by use of trained mediators. By passing more responsibility for conflict resolution to local and community levels, government authorities at higher levels (bureaucracies), legislatures, and the courts will be relieved of some of the burden. This will also reduce protracted interagency discussions, efforts to influence political decisions, and the polarization that results when court or policy decisions or the enactment of laws create clear winners and losers. Such polarization inevitably results in temporary solutions, as losers pursue advantage in the next round.

3) *Ally science with policy making independent of the interests of resource users.*

Scientific and technical data about wild living resources are often interpreted to support the interests of stakeholders or subordinated to protect political interests. Science used in policy will likely not work if scientific consensus is forced, as often happens in the scientific committees of international commissions (Mangel et al. 1993), and policy itself is most effective when it is built on broad consensus. Better employment of scientific data can increase the capacity of policy makers to explore the full range of options. This preferable policy-making process can be undermined when scientists are subordinated by political interests, made largely accountable to managers, or retained by stakeholders to support their perspectives. By placing science in closer proximity to policy makers, independent of management and stakeholder interests, the value of scientific information can be considerably increased. Potential conflicts in advice among "expert" sectors should be resolved insofar as possible before advice is presented to legislators, courts, or other authorities. Where expert views are not resolved, assumptions, uncertainties, and risks should be clearly presented. Expert views should be subject to broad-based peer review. For the reasons noted earlier (see *Principle V*; mechanism 2, above), scientists should be careful to differentiate between scientific fact and judgments regarding management practices or policies. Failure to do so can jeopardize the credibility of science and the scientist and allow decision makers to avoid being fully accountable for their decisions.

4) *Require that policy makers be held accountable for the use of the best possible data and analyses in setting policy.*

Because of inherent uncertainty in ecological, economic, and social systems, changes are required in the way decision options are evaluated. First, decision makers should go beyond examining how uncertainties may affect the potential distribution of outcomes, and focus on how uncertainties may influence the choice of one decision over another, given the management objective. Second, society must judge the quality of decisions not only on the basis of observed outcomes, but also on the quality of the data and the process used in making a decision. Third, the decision process must be documented in a transparent manner, to allow the policy maker and technical specialists involved to be held accountable for their decisions and advice. Fourth, effective policy may require taking actions that are sub-optimal in the short term, in order to generate long-term information that will improve future management or will ease the social and economic costs of policy change. For example, an experiment on groundfish currently underway in Australia (Sainsbury 1991, McAllister and Peterman 1992) should generate useful information on the relative likelihood of different hypotheses about community structure and dynamics; this knowledge will improve future management.

Scientists are not the center of policy making and should not be used for setting the goals of the community. Policy makers should neither ask for firm conclusions when they do not exist, nor interpret scientific results to suit preferred policy outcomes. Scientists must characterize risks and uncertainties in terms a lay person can respond to, and indicate realistic time frames in which risks may occur or uncertainties be resolved. It is the responsibility of scientists to ensure that the executive summaries and other abstracts of scientific assessments likely to be reviewed by policy makers and the public give full expression to uncertainties and risks.

5) *Insofar as possible, establish agreed-upon criteria and procedures to guide decision making on conservation measures at all levels, in order to reduce the scope for influence by political or special interests.*

A decision that is arrived at by the application of predetermined and well-reasoned rules is less susceptible to being overridden by special interests. Too often, limits concerning the use of a resource are a compromise between what is viewed by scientists as justifiable given the available data and what is demanded by the interest groups. Limits on use are therefore often based on socio-economic factors rather than biological considerations, usually resulting in a decline of the resource. Methods to avoid this problem must be developed.

One possible method is to ensure that all stakeholders are aware of the uncertainties and the potential long-term consequences of uncertainties concerning the possible costs and benefits of resource use. In addition, stakeholders should have a common understanding of what constitutes evidence of unacceptable use-related effects and should agree beforehand on what will be done if evidence of such unacceptable effects becomes apparent. In the case of fisheries, for example, it could be agreed that a fixed decline in catch per unit of effort (or some other index or monitored variable) constitutes evidence of an unacceptable effect and that if this is observed, it will automatically trigger a fixed reduction in fishing effort, or some other management response. Establishment of such predetermined decision rules can reduce the risk of short-term socio-economic considerations overriding long-term biological and ecological considerations. Computer simulations can be used to help evaluate and select such appropriate decision rules. As with any management scheme, the status of the resource and related ecosystem components should be kept under review, and the management plan should be revised if it does not work as expected.

6) *Ensure that formal institutions responsible for giving expression to policies and implementing conservation programs have temporal and spatial perspectives consistent with the ecological character of the resources and organizational structures that are (1) flexible and problem-oriented; (2) accountable, visible, and performance-oriented with clear, measurable, and explicit objectives; (3) team-oriented, participatory, and interdisciplinary, employing consensual decision-making; and (4) capable of learning and corrective feedback (i.e., are adaptive).*

Institutions often lack spatial and temporal definitions of their missions congruent with that of users, stakeholders, or the ecology of the resource (Kellert and Clark 1991). For example, the cumulative impact of many discrete actions often has ecosystem effects not compatible with a management focus on a single fiscal year or a single location. Failure can take a number of forms, including failures of integration or of specificity, failures of scale and priority, and failures of feedback. Many policy failures can be tied to incomplete specification of organizational goals, incentive and reward deficiencies, conflicting directives and organizational objectives, limited competence and training, conflicting interests and agendas, lack of enforcement capability, fragmented decision-making and accountability, rigid and defensive communication structures, poor public involvement, or lack of high-quality information (Dowell and Wange 1986). Understanding the organizational behavior of regulatory institutions is thus a key to improving the effectiveness of conservation policy (Yaffee 1982, Clarke and McCool 1985).

Various internal and external factors affect organizational behavior. Internal factors include goals and objectives, standards and measures of performance, incentive and reward systems, leadership and authority structures, information and communication flows, specialization and role relationships, culture, and ideology. External factors include the sources of funding, ally and adversarial relationships, the influence of politicians, public perception, and the media. We require clearer and more explicit institutional problem definition, enhanced organizational coordination and cooperation, fuller participation of all relevant interests, greater accountability and incentives for success, and increased institutional adaptability and learning capacity. Successful conservation requires reconciliation of spatial and temporal perspectives among management agencies, relevant stakeholders, and the ecological character of the resource.

Principle VII. Effective conservation requires communication that is interactive, reciprocal, and continuous

Effective communication can greatly enhance prospects for effective conservation by allowing stakeholders to understand the problems and the potential results of alternative courses of action. Communications among scientists, the public, and decision makers are sometimes problematic. Two-way, interactive, open, ongoing communication serves all interests better by bringing expectations into alignment. There is virtually unlimited opportunity for misunderstanding through failed communication, so substantial effort is required to ensure effective communication.

The following mechanisms will help implement this principle:

1) *Ensure that communication is targeted to the audience and is based on mutual respect and sound information.*

Mutual respect requires clear, objective, and honest presentations with breadth and depth tailored to the target audience. Where differences of language and culture exist, it is important that all involved make an effort to overcome them. The same is true of communications among those specialized in different disciplines. Practitioners have professional cultures, and without an appreciation of such cultural differences, communications will be more difficult and less productive.

A higher information content at the outset of communication, with clearly stated goals and objectives, will reduce misinterpretations. Scientific assessments should specify in ecological and socio-economic terms the causes and effects of the conservation problem and the costs, benefits, and risks of different solutions. Where uncertainties exist, these should be clearly communicated, together with potential consequences, so as not to undermine the credibility and usefulness of science and scientists in the policy process (Bolin 1994). An iterative, two-way process is essential to identify misperceptions and needs for clarification. For example, the scientific process involves ongoing testing and self-correction, whereas decision makers must act decisively, and with assurance, within relatively short time frames. Similarly, the standard of proof for a scientist may differ considerably from that required by a court of law.

2) *Require internal and external review to verify objectivity and results.*

Since the credibility of communications will erode unless the contents are independently verified, each practitioner must be responsible for ensuring the validity of information communicated. Just as a scientist should submit to peer review, a journalist should check with different sources. Policy-makers and managers should be responsible for ensuring that assessments are based on sound information and receive external review. The review process should extend to those well versed in socio-economic and biophysical disciplines, and familiar with the particular operational circumstances. Regular review deepens understanding of issues and uncertainties, and of different professional cultures. In addition, it highlights changes in scientific and technical understanding and the results of policies made and decisions taken.

3) *Inform and motivate the public and motivate regarding conservation.*

The motivations of stakeholders ultimately determine the success of conservation efforts. Information should be provided to enhance the public's capacity to render informed and intelligent opinions consistent with conservation. Too often, input is solicited at too late a stage for policy makers to take the views of the public into account. Similarly, often too little attention is given to educating the public about what to expect from management and from the resources themselves.

Educational programs at all levels should emphasize transdisciplinary problem definition and solving. Forums that encourage interaction and feedback are more likely to reveal unstated assumptions and values, clarify objectives, and highlight areas of uncertainty than forums that do not encourage such interaction. Recognizing that people learn differently, the same information needs to be presented to different target audiences in different ways. Development of professional skills should include training in the appropriate use of specialized communications techniques and technologies. Funding for communications training and communications should be included in the costs of conservation programs.

4) *Develop institutions and procedures to facilitate transdisciplinary analysis and communication that informs decision makers.*

More attention must be paid to developing the skills necessary to facilitate transdisciplinary communication. To participate in such communication effectively, one needs a basic understanding of how questions are approached in different disciplines. Managers and research institutions should define terms of reference and procedures for transdisciplinary studies that foster interaction and balanced products. The academic community should promote transdisciplinary problem-solving among students and develop criteria for tenure and promotion that reward transdisciplinary work.

Models, when perceived as quantitative descriptions of current understanding, can be an especially effective form of communication. They can help create a common language and explore the consequences of the best-understood information, in order to communicate the likely outcomes of alternative actions and help in the search for trade-offs. For example, models have been used to understand, in the absence of critical data, mobbing in Hawaiian monk seals (Starfield et al. 1995), and to choose management strategies in response to this behavior (Ralls and Starfield 1995). Similarly, a population model for management of the saiga antelope (Milner-Gulland 1994) allows users to evaluate the possible impacts of different management strategies and shows the importance of considering climatic fluctuations when choosing harvest levels.

Summary

All conservation problems have scientific, social, and economic aspects. The relative mix will vary, but it is essential to recognize all three components. Furthermore:

• A basic component of almost every conservation problem is human population growth and resource consumption.
• At this time, true ecosystem management is not yet practical, but an ecosystem approach in which one thinks comprehensively in terms of the interconnectedness of effects is mandatory.
• Individuals active in conservation should develop an understanding of all relevant fields, as appropriate, in order to communicate more effectively with colleagues.
• Conservation problems do not have simple solutions and one must avoid thinking that the next technique (e.g., food-web theory, GIS, DNA finger-printing) will complete the tool-kit for resource conservation.
• Uncertainty must imply conservatism, but in a manner that promotes improved understanding.
• The disparity between economic and ecological time scales presents a great challenge because the economic system responds to change much faster than the ecological system; that is, biological systems are constrained by much slower time scales than economic systems. Furthermore, modern communications allow economic decisions to be made far from the actual location of the conservation problem, with no local community input, and to be implemented rapidly. Analytical means and management institutions capable of ensuring that the extremely rapid economic time scales do not overtake the biological ones are required.
• Many of the values attached to living resources that are commonly seen as non-economic are economic in that people are willing to commit resources on the basis of such values. Resources have scientific, ecological, aesthetic, and functional values that are not expressed in the market place. Adequately identifying and effectively measuring all relevant consumptive and non-consumptive values of varying stakeholders is a non-trivial and complex matter, but it must be undertaken. Not all species or ecosystems are equally valuable and this requires facing the "agony of choice."
• Conservation requires a transparent process of decision making that engenders public faith in the credibility of the process and thereby brings the public and decision makers to better understand the desirability, from all perspectives, of maintaining the resource, particularly when it is subject to continued use.
• Decision makers should be evaluated on their decision process and on the data they use, rather than merely on the outcome. The process must be capable of fairly taking into account different values and interests, defining and responding to specific problems at appropriate temporal and spatial scales, and adapting quickly to new information and analyses.
• Effective policy may require taking actions that are sub-optimal in the short term, in order to generate information that will improve future utilization and conservation.
• Understanding the organizational behavior of regulatory institutions is a key to improving the effectiveness of conservation policy, and institutional accountability is fundamental to effective conservation.
• Although good scientific input is essential if one is to address successfully most conservation problems, it is usually not sufficient in and of itself, and scientists should not be asked to set the policy goals of and values for the community. Scientific consensus, while it is highly desirable, should not be forced and policy makers should neither ask for firm conclusions when they do not exist nor incorrectly interpret scientific results to support preferred policy outcomes.
• The concept of a "right to use the resource" must be changed; it must be seen as the "privilege to use the resource." Users should pay for the right of access to public resources, in order to assure funding for conservation activities, management, and data collection, and to reduce chances of misuse of the resource. Pos-

itive incentives for conservation are as important as paying for the right to use the resource.

• The initial hypothesis concerning the possible effects of resource use should be that until proven otherwise resource use will damage the resource and the related ecosystem. The burden of proof should be shifted from the regulatory body having to show that use will have a detrimental effect to the user to show that use will not have a detrimental effect.

• Procedures for dispute resolution must avoid the dangers of management based on averaging the positions of all stakeholders.

• Two-way, open, interdisciplinary, and transparent communication can greatly aid conservation efforts, and such communication must be based on mutual respect.

Treating wild living resources as has been done in the past is untenable for the long term. The fundamental relationship between people and the rest of nature needs to be rethought, and policies developed that fully recognize the realities of the biophysical constraints under which humans must function. The principles and mechanisms presented here provide the guidance for such a change and it is now time to put them into action to prevent degradation and ultimate destruction of the natural resources and ecosystems on which the human species depends.

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—*Marc Mangel*

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APPENDIX I

Living-Resource Conservation: An International Overview[4]

Introduction

This appendix contains the results of an extensive series of consultations held in 1992, 1993, and 1994 as part of the Marine Mammal Commission project on Living Resource Conservation. The purpose was to obtain a global overview of the current status of conservation of wild living resources to serve as background for a workshop held in March 1994 at Airlie House, Virginia, USA. The results are presented in the form of a synthesis of the relevant experience, insights, and understandings as expressed by researchers and managers throughout the world.

In 1992, on behalf of the U.S. Marine Mammal Commission, I undertook a program of consultations with key individuals in both research and management, with the following objectives:

1) to review what has happened since 1975 (Holt and Talbot 1978) to the stocks of living resources, including management performance (theory and practice) and scientific knowledge and technology;

2) to determine whether the principles described in 1975 are still valid today and how they should be augmented or modified;

3) to identify what needs to be done to have the principles implemented, i.e., what have been the obstacles to such implementation and how can they be overcome; and

4) to find ways to make the principles operational.

Scope

"Living resources" refers to aquatic and terrestrial animals and plants that are free-living, i.e., that are not intensively farmed or cultivated. Therefore it includes marine mammals, marine and freshwater fishes, other aquatic vertebrates, invertebrates, and plants; and terrestrial mammals, birds, other vertebrates, invertebrates, and plants.

"Conservation" is used with the connotation of consumptive and non-consumptive use, sustainability (in the sense of sustaining the resource so that it is available for future use, or maintaining future options), and management for both consumptive and non-consumptive purposes.

Methods

To obtain an authoritative global overview, the author consulted as many as possible of the key scientists and managers who are involved with conservation of living resources throughout the world. While consultation by correspondence can yield important information, direct, face-to-face meetings provide the opportunity for much more flexible, in-depth, and comprehensive communication, particularly in view of the great diversity of resources, management philosophies and approaches, and economic, social and ecological conditions.

Consultations were carried out in Africa, Asia, Australasia, Europe, North America, the Pacific, and the Caribbean. Over 380 individuals were consulted from these and other areas including Central and South America. Those consulted[5] represent a large proportion of the individuals, worldwide, who study, manage, or are otherwise directly involved with conservation of wild living resources, The consultees are from 33 nations—10 from the Americas, 7 from Asia and Australasia, 4 from Africa, and 12 from Europe. However, the direct field experience of those consulted is truly global.

About 53% of those consulted were directly involved with science through scientific research or other academic endeavor, and ≈47% were involved with management, administration, or decision making in connection with wild living resources. Approximately 64% of the second group currently were in resource management positions, per se.

Since the project was concerned with all wild living resources, one objective in the choice of persons to consult was to assure that the different types of resources were adequately represented. The percentages of those consulted who can be categorized by a current resource specialty is as follows: marine mammals—9%; marine fisheries—26%; marine living resources in general—19%; freshwater fisheries—4%; terrestrial wildlife—26%; forests, rangelands, and other vegetation—16%.

Therefore, ≈54% specialized in marine resources and 46% in terrestrial, including freshwater, resources. However, many were not in the above list because they were not specialized in only one category of living resource. Consequently, these figures only very roughly indicate the mix of expertise consulted.

This report briefly summarizes the points raised in the consultations. The records of the discussions fill several notebooks and I have sought to distill this information and opinion into a report that is short enough to convey usefully the key points. I take full responsibility for the processes of interpretation and summarization of the substance of the consultations. However, the comments received on a Preliminary Report which was sent to all consultees, and on two subsequent drafts, have provided an extensive review of the accuracy and completeness of the process. The present report incorporates relevant advice received from these extensive reviews.

There was not unanimous agreement on all points, including some of the examples given, and key areas of disagreement are noted in this report. However, these areas are relatively few since there was wide agreement on most issues.

A New Perspective

Since the 1970s there have been dramatic changes in the understanding of and approach to conservation of living resources. The underlying assumption of most of those involved with wild living resources at that time was that it was possible to manage living resources on a sustainable basis and that the only question was how to achieve this. They regarded that question primarily as a scientific issue, with the key components to be considered including the ecological and more narrowly biological information about the species or stocks involved, their ecosystems, and the scientific analysis of those data to develop management regimes.

However, most of those consulted in the present project had a very different perspective. Many questioned whether it is possible to achieve sustainable management of most living resources, at least in terms of economically viable commercial harvest, but also in many cases in terms of other consumptive and non-consumptive conservation objectives ranging from sport hunting and fishing to preservation. Beyond the obvious, continued decline in most living resources, there appear to be two major reasons for this dramatic change in perspective.

The first is a change in the way ecosystems are perceived. Some call this "the new ecological paradigm." It should be emphasized that although the facts have been known by some ecologists, other scientists, and managers for many years, it is only recently that there is more widespread rec-

[4] Authored by Lee M. Talbot.

[5] The list of those consulted is on file with the Marine Mammal Commission, 1825 Connecticut Avenue NW, Washington, D.C. 20009 USA.

ognition and acceptance of the knowledge. Formerly the dominant paradigm was that of an ecosystem that was stable, closed, and internally regulated and that behaved in a deterministic manner. The new paradigm is of a much more open system, one that is in a constant state of flux, usually without long-term stability, and affected by a series of human and other, often stochastic, factors, many originating outside of the ecosystem itself. As a result the ecosystem is recognized as probabilistic and multi-causal rather than deterministic and homeostatic; it is characterized by uncertainty rather than the opposite. Two types of uncertainty are involved in living-resource conservation. The first could be considered "ecological uncertainty," which refers to the probabilistic nature of biological systems discussed in the previous paragraph. The second type is uncertainty in the estimation of parameters such as abundance, birth and death rates, etc.; this is "measurement uncertainty." Both of these types of uncertainty are central concerns to any model or management regime, but there is often confusion between them when uncertainty is discussed.

The second factor is the recognition of the fundamental role of social and economic factors in determining what the goals of management will be and what management actions will be taken. Socio-economic factors normally determine whether or not a management regime will be implemented, regardless of how sound it is scientifically. And at a more basic level, it is the motivations of the users or managers that determine whether or not a living resource will be conserved or lost.

There are two main practical implications of this new perspective. First, management must recognize ecological uncertainty as an overriding factor, even to the uncertainty as to whether it is possible to achieve the consumptive or non-consumptive objectives of management. Second, any approach to management that does not take the socio-economic factors into account probably will not succeed.

Key Issues

Those consulted expressed virtually unanimous concern for the future of most living resources throughout the world. Consequently, there was strong agreement that there is an increasingly critical need to define principles for the conservation of living resources, and, more important, to implement those principles without delay. There was also agreement that the same basic principles apply in general to all living resources—aquatic or terrestrial, animal or plant. There are, however, significant differences in how the principles must be implemented for different types of living resources. These differences are less related to the type of living resource than to its characteristics, such as whether it is resident or migratory, its location relative to management authority (i.e., within the jurisdiction of a single authority, several authorities, or in the "commons" under no single authority), and the characteristics of its population dynamics and ecological relationships that affect its response to management.

Most species and stocks of wild living resources (as contrasted with living resources that are ranched, farmed, or managed in some form of plantation) that are being harvested commercially have been or are being depleted. While habitat change is often a contributing factor, the harvest itself is regarded as the principal cause of depletion. In contrast, some stocks and species that are being managed for sport hunting or fishing appear to be managed sustainably (although in some cases this is accomplished by restocking rather than wholly by natural reproduction).

Where there is depletion of species and stocks that are not commercially harvested, the main factor appears to be habitat change. In the same way, those species being managed for non-consumptive uses (i.e., for viewing or to protect endangered species) are most usually depleted or threatened because of factors in the ecosystem ranging from simple destruction or degradation of habitat through competition for food (often by human exploitation of the food source) or incidental mortality from other human exploitation activities such as by-catch (incidental take) in fisheries.

The principles defined in 1975 are considered by all those consulted to remain basically valid, and the main criticism is that they have not been implemented. There was also much agreement that the statements of principle should be augmented by explanations of the ways in which the principles could be implemented, and that there should be some expansions in the discussion of the present principles. Two major augmentations or additional principles were recommended. One concerns socio-economic factors, which are regarded as key to whether or not any principles are implemented. The other involves uncertainty, i.e., the fact that ecosystems (and hence, the species within them and their response to management) do not behave in deterministic ways and are not stable. Therefore it is not possible to predict with certainty the effect of management, and the focus of research and management should be to identify the risks and define ways to manage conservatively in the face of uncertainty.

The main obstacles to implementation of principles that were identified by those consulted lie in the area of motivation, i.e., what is the reason for the management or what are the competing reasons. In large part these reasons are economic, e.g., in the cases where the objective of management is to obtain the maximum short-term economic gain. This issue is aggravated by the differences between the time scales of politicians and industries and the time scales involved in resource dynamics. The second major obstacle cited was politics and decision making, which are effectively the ways in which the motivations for management are expressed. In other words, political decisions which lead to depletion of the resources derive from and reflect the original motivations for management of those resources. A third major obstacle involves policy, law, and institutional arrangements, all of which, in turn, derive from the political decisions; they are the way society seeks to implement the decisions. Consequently, what were considered to be the major obstacles to sustainable management of living resources all reflect or derive from the original motivations for that management. It follows that the primary approach to overcoming those obstacles requires addressing the issues of motivation.

Scientific knowledge is essential to provide the foundation for effective management, but relative to the motivation-linked issues, science plays a supportive role. On the one hand, more scientific information is needed in almost all cases. On the other hand, there is usually enough information to provide needed guidance to take some action without delay—if that information is provided effectively and within the context of uncertainty and risk assessment. Postponement of management decisions until scientific certainty is reached leads to management failure. This role of science often will require a significant change in the approach to the science, art, and operations of management, and a change in the approach of many scientists and managers.

The "New Principles" of the 1970s called for an approach that takes the ecosystem into account. However, while the ecosystem approach is much discussed there have been very few attempts to apply it. There is a distinction between an *ecosystem approach* and *ecosystem management*. The first implies management (e.g., of a target species) that takes the ecosystem into account. A comprehensive ecosystem approach would require consideration both of the effects of management on other species and on the ecosystem itself. Ecosystem management has been used both to refer to an ecosystem approach as discussed above, and to managing the ecosystem itself. Many questioned whether we are talking about managing ecosystems or managing what people do with ecosystems. Ecosystem management, per se, probably is most widely attempted in connection with management of terrestrial and marine parks and other protected areas.

However, some of those consulted felt that we simply do not have the understanding, resources, or capabilities to manage ecosystems, and that discussion of ecosystem management is a diversion from the urgent business of managing species. They doubt our ability at present to deal with ecosystems and believe that there are very few cases of understanding or monitoring even a single species well, much less multiple species or the ecosystem itself. However, there is broad agreement that having the ecosystem approach as a goal is important, particularly to guide thinking and research, and to serve the function of a guiding principle.

Growth of the human population was nearly always mentioned as a major obstacle to long-term or effective conservation of living resources. Increasing human population numbers mean increasing demands on resources, and sustainability of any living resource cannot be achieved in the face of constantly increasing harvests. More important, the increasing population exerts increasing pressure and change on the face of the earth. The physical changes along with associated factors such as pollution, ozone depletion, and climate change all lead to increasingly critical changes in the ecosystems on which living resources rely. An associated consideration is that scant attention will be paid to living-resource conservation in situations where peoples and their governments must struggle to increase food production and economic and social development to keep pace with a constantly increasing population. While management of human populations is beyond the scope of this project, continued human population increase represents a major obstacle to effective conservation of living resources.

APPENDIX II

Developments since 1978 that Prompted Reanalysis of the Original Principles

Among other things, developments in four areas motivated re-examination of the 1978 principles. These developments were elaborated by the workshop participants as follows.

Developments in Ecological and Biological Understanding

Since the 1970s there have been considerable changes in the ways in which ecosystems and their component parts are perceived. Focus on endangered individuals and species expanded from localized sites to a broad landscape perspective. A parallel expansion in the perception of threats to ecological integrity led to a global focus, reflecting a recognition and concern for global-scale phenomena such as climate change and ozone depletion. There is now recognition that efforts to deal with ecosystems must be done on an appropriate temporal and spatial scale and that ecological processes are not largely equilibrial and predictable, but are dynamic and probabilistic.

Twenty years ago, the extremely high rates of extinction and their implications were not widely understood as affecting the full range of taxa. This realization (Myers 1979, Lovejoy 1980) led to broadened recognition of what needs to be conserved: not just species that people exploit or admire, not even the habitats of those particular species, but the full range of biological diversity (Norse and McManus 1980). Diversity in biological systems occurs at all levels, from genes through ecosystems, and it is important to aim to avoid losses at all levels (Norse et al. 1986). Moreover, the integrity (sensu Karr 1992) of the biological systems and the processes that sustain their diversity must be maintained. For example, 20 yr ago there was little discussion about maintaining subterranean fungi, let alone their relationships with vascular plants and the animal-mediated dispersal processes that ensure the continuity of these relationships. The new, broader focus is on the entire catalogue of "parts" and the processes that connect them.

Conservation biology (Soulé 1986, Primack 1993, Meffe and Carroll 1994) and landscape ecology (Forman and Godron 1986) draw upon many biological disciplines and synthesize and highlight ideas such as:

- biological systems are highly variable and dynamic and many species and ecosystems depend on disturbance;
- because species are often linked with one another, removal of species at one level can have unanticipated changes (May et al. 1979, Pimm 1991);
- some places are disproportionately important, either because they are high in diversity (Myers 1988), have crucial resources used by a wide variety of species, or are important for particular stages of an organism's life history;
- some areas are sources of colonists, with the result that other local populations can be subject to high rates of extinction, but can be replaced by colonists from these source populations (Murphy et al. 1990);
- some species are disproportionately important in their ecosystems (Gilbert 1980, Mills et al. 1993);
- understanding life histories may be central to conservation; small populations are subject to a variety of demographic problems that threaten them in the short term and to genetic problems that may threaten them over the long term (Shaffer 1981);
- conservation efforts need to be scaled to natural spatial and temporal patterns (Caughley 1994);
- fragmented ecosystems are often like islands, and are vulnerable for many of the same reasons (Diamond 1975);
- corridors that connect ecosystems have important implications for conservation (Noss 1987);
- alien species are often a threat to native species (Drake et al. 1989);
- not all threats are local; some threats, such as atmospheric change, affect the entire globe, albeit differently in different places (Pters and Lovejoy 1992).

Recent comparative studies of marine systems develop a focus on stress mitigation and management priorities where primary, secondary and tertiary causes of biomass yields have been determined, based on varying levels of over-exploitation, pollution, and natural perturbations (Mee 1992, Bakun 1993, Sherman 1992).

Developments in Economics

Developments in economics having special relevance are: (1) the emergence of bioeconomics (Clark 1990) and ecological economics (Costanza et al. 1993); (2) the development of methods for identifying the conditions under which ecological–economic systems may yield a continuous flow of benefits; (3) the application of the theory of games to questions concerning international resources; and (4) the development of new techniques for the valuation of non-market resources.

Ecological–economic systems comprise both the economic activities and the biogeophysical processes on which those activities are based. An important property of ecological–economic systems is that as the economic system grows, the dynamics of the joint system are increasingly nonlinear and discontinuous (Braat and van Lierop 1987), and feedback is pervasive in such systems (Perrings 1991). When the feedback is positive, change in one system is similarly reflected in the other. When the feedback is negative, change in one system may dampen change in the other. Progress has been made in the characterization of the persistent states of such systems, and in identifying thresholds between these states (for examples drawn from dry lands see Friedel [1991] or Laycock [1991]). Similarly, attention is now directed to substitutability of resources as we shift from the situation in which human-made capital is the limiting factor to one in which natural capital is the limiting factor (Daly 1993). Recent work (Solow 1986, Hartwick 1992) shows the critical importance of the limits to substitutability; wild living resources are assets for which there are few or no substitutes. The list of such assets includes not only the genetic properties of individual organisms, but the ecosystems that are supported by the mix of organisms (Holling et al. 1995).

Ecological economics investigates the conditions in which the joint system can maintain its productive potential over time, analogous to the study of resilience in ecology (Holling 1973, 1986) or the theory of capital in economics (Victor 1991). Economic development is truly sustainable only if the total value of the asset base is non-declining over time, since this ensures that future generations will have the same consumption possibilities as the present generation. Similarly, ecological systems are truly sustainable only if they maintain function under the range of conditions of use (Common and Perrings 1992).

Feedback effects in economic systems (Arthur 1990) include changes in human preferences and technology, and these vary with economic growth. Ecological values may also change as people understand how property rights are affected by the behavior of the ecological system. Preferences, technology, markets, and property rights may all change in response to the environmental effects of economic activities.

Most international environmental agreements concerning use of biological resources are predicated on the sovereign rights of individual states over the resources in the domain. If this is the case, although individual countries can potentially be made better off by cooperating on environmental matters, cooperation will only occur if they are actually made better off. Recent research has identified the conditions under which cooperation for the conservation of natural assets can be maintained in a self-enforcing international agreement (Barrett, *in press*).

Methodology for the valuation of non-market environmental resources is still comparatively new (Fisher and Hanemann 1986, Knetsch 1990, Kolstad and Braden 1991, Coker and Richards 1992). A new technique provides a means of estimating use values from both an economic and ecological perspective (Barbier 1994) and thus allows exploration of the significance of economic activities that affect the resilience of ecological systems.

Developments in Institutions

It is now apparent that established institutions do not adequately promote solution of the problems of conservation. However, there are social instruments and policies that can facilitate the task of changing our individual and collective behavior. These may be based on changing values or on incentives and disincentives, including enforcement measures, such as those used to implement the Endangered Species Act of 1973 and the CITES treaty of 1973. There are some species for which general society chose to abandon virtually all consumptive uses; mechanisms for doing so evolved in a haphazard way over the last 20 yr. For example, the direct commercial exploitation of marine mammals has declined over the past 20 yr, due in part to changing values and in part to the adoption of a global moratorium on commercial whaling by the International Whaling Commission in the 1980s. It is now time to formalize mechanisms for such changes.

When resources are used non-exclusively, most institutional arrangements will involve regulation of access by society. A recent policy development is the concept of "ecological user fees" as a means of limiting the use of ecosystems threatened by biodiversity loss (Costanza and Perrings 1990, Pearce and Turner 1990). Property rights in the ecosystem rest with society as a whole, but individuals may be granted the privilege of use and charged a fee equal to the social value of their use of the resource. The same result may, in principle, be obtained by levying a tax on marketed goods or services deriving from the ecosystems (Baumol and Oates 1988).

Perhaps the most effective means yet devised for managing ecological resources in the public domain is the Individual Transferable Quota (ITQ). Many marine fisheries that fall within a single jurisdiction are managed on this basis, which has the merit of encouraging efficiency in the allocation of resources within overall limits (Neher et al. 1989). Analogous systems have been applied to the problem of atmospheric pollution (Tietenberg 1990). The introduction of transferable quotas subject to well-defined and secure property rights is one of the most important policy innovations in the management of living resources since 1978. While some ITQ schemes have failed, others had a very strong and positive impact on both the efficiency of use and persistence of the resource.

It has also become clear that, in general, existing decision making and management institutions cannot easily take into account competing uses or the temporal and spatial viewpoint required for effective conservation. The "200-mile Exclusive Economic Zones" (EEZs) (Juda 1991) adopted at approximately the same time as the 1978 principles appeared had profound effects on the institutional structures for implementing conservation principles. By extending the responsibility of national governments to manage and conserve resources out to 200 miles ($\approx$322 km), the establishment of EEZs transferred the bulk of authority for the management of marine living resources from international institutions or agreements to national governments. The rationale for doing so was to avoid the "tragedy of the commons" by vesting responsibility in coastal states. However, this transfer did not modify the predominant motivation of coastal fishing interests, which was to limit exploitation of the resource to coastal interests. Consequently, national management efforts were no more successful than previous international ones in conserving the resources. In the 5-yr period following the creation of an EEZ or Exclusive Fishery Zone, 66% of states experienced increased catch, but 32% experienced decreased catch, and the rest had no change (Juda 1991). The motivations leading to over-exploitation of the fish stock and over-capitalization of the industry did not change, and national management institutions are only now beginning to deal with those problems (Juda 1991).

Ethically it is now clear that engaging stakeholders in formulating and implementing policy and management decisions is valuable. The challenge is to involve the stakeholders in a manner that leads to long-term conservation, rather than short-term over-exploitation. Similarly, maintaining close connections between science and policy is desirable but often difficult and uncertain in large bureaucracies where management, user interests, and scientists are rarely placed together. The electric-utility commissions in many of the U.S. states and in Canada have developed a workable compromise. They hold quasi-judicial hearings to obtain informed input and then the panel of commissioners uses that input to make decisions concerning the resource.

Thus, it is as important to identify sociological and institutional implications of conservation principles as it is to ensure that the principles themselves are economically and scientifically correct. The category of problems is one in which both the level of fundamental uncertainty and the potential costs to society are high. This places such problems in the realm of what Funtowicz and Ravetz (1993) have referred to as "post-normal science," where ethical judgments are ubiquitous.

Developments in Technology and Methodologies

Developments in technology and methodologies that bear on the conservation of living resources include advances in computer technology such as data handling, communications, modeling, risk analysis, and geographic information systems. Remote sensing now includes the use of satellites and other technology. Molecular biology and genetic analyses permit identifying individuals and stocks and determining the level of their relatedness. A broader understanding of physiology now allows us to identify, among other things, the effects of possible toxins. There are enhanced techniques for marking and tagging that permit the acquisition and rapid communication of new kinds of data.

Developments in the technology associated with financial markets mean that economic transactions now occur almost instantaneously and at any distance from the affected resource or ecosystem. This presents a great challenge to conservation because biological systems are constrained by much slower time scales and it is imperative that extremely rapid economic time scales do not overtake biological ones.

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