Tenets, Principles, and Criteria for Management: The Basis for Systemic Management

CHARLES W. FOWLER

Introduction

Ecosystem management has been vigorously debated at many meetings, conferences, and workshops (Interagency Ecosystem Management Task Force, 1995; Malone, 1995; Stanley, 1995; Christensen et al., 1996; Mangel et al., 1996; Schramm and Hubert, 1996; Czech and Krausman, 1997; NMFS, 1999; McCormick, 1999). The resulting volume of literature contains lists of tenets (requirements, demands, or criteria, reviewed in Appendix 1) as progress toward an appropriate form of management. Recent panels and commissions have urged their implementation (Pew Oceans Commission, 2003; U.S. Commission on Ocean Policy[1]).

Part of this effort has been a reaction to the realization that conventional resource management schemes have too often failed and need to be

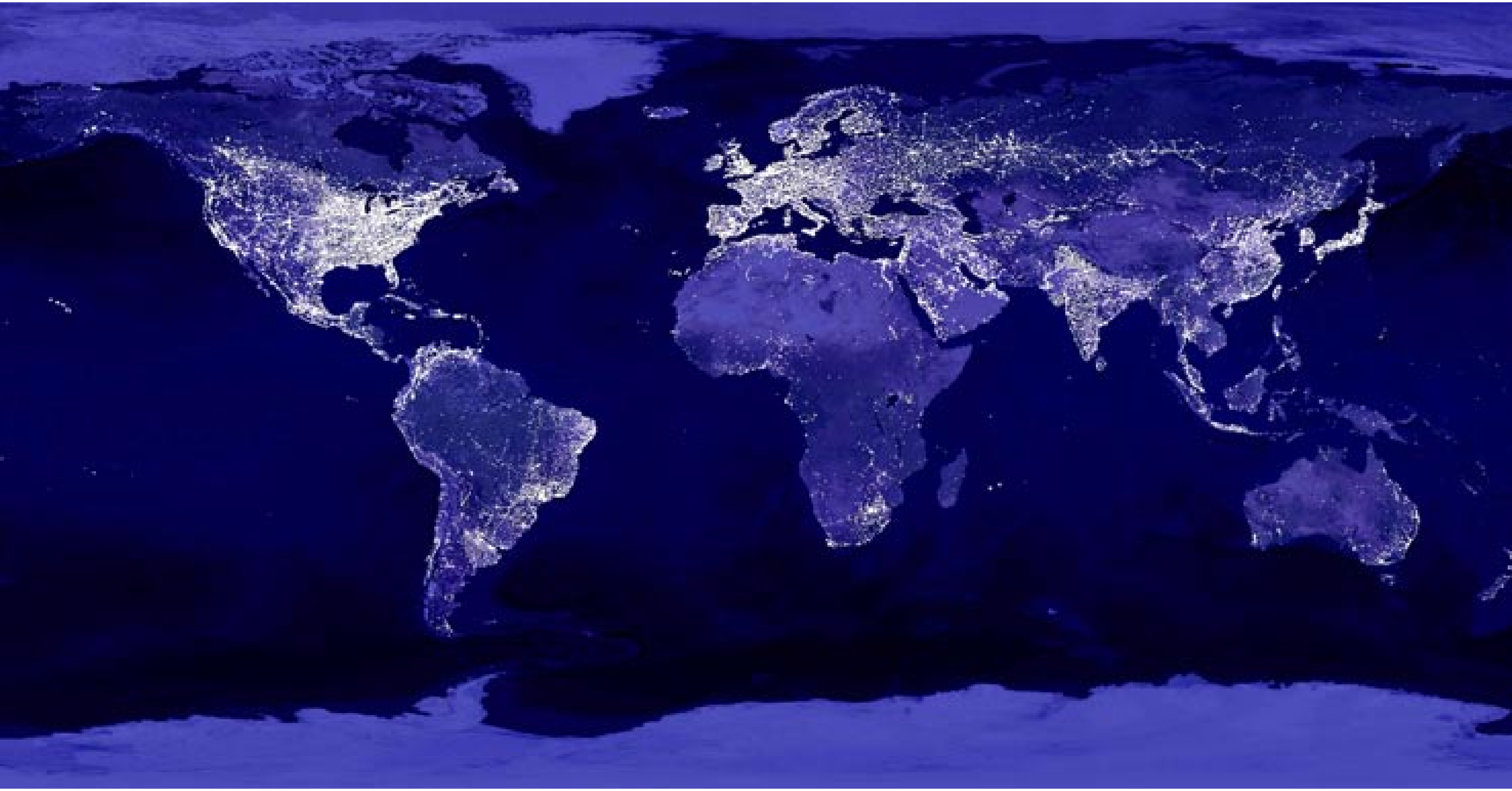
[1]An ocean blueprint for the 21st century. Final Report of the U.S. Commission on Ocean Policy, 1120 20th Street, NW, Suite 200 North, Washington, D.C. 20036.

Charles Fowler is with the National Marine Mammal Laboratory at the Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA, 7600 Sand Point Way N.E., Seattle, WA 98115 [e-mail: Charles.Fowler@noaa.gov]. Views expressed in this article do not necessarily reflect those of the National Marine Fisheries Service, NOAA.

ABSTRACT—This paper presents nine tenets for management as formulated in the literature in recent decades. These tenets, and the principles behind them, form the foundation for systemic management. All tenets are interrelated and far from mutually exclusive or discrete. When we consider them seriously and simultaneously, these tenets expose serious flaws of conventional resource management and define systemic management. Systemic management requires that we manage inclusively and avoid restricting management to any particular interaction between humans and other elements of nature.

The management tenets presented here are considered with particular attention to the interrelationships among both the tenets and principles upon which they are based. The case is made that the tenets are inseparable and should be applied collectively. Combined consideration of the tenets clarifies the role of science, contributes to progress in defining management, and leads to the development of ways we can avoid mistakes of past management. Systemic management emerges as at least one form of management that will consistently account for and apply to the complexities of nature.

The planet Earth, a tiny island in our solar system, galaxy, and universe, supports a living system known as the biosphere, a relatively thin layer near the surface. The biosphere is one of the systems affected by human activities—a system to be considered in management (Photo courtesy of NASA/GSFC/NOAA/USGS).

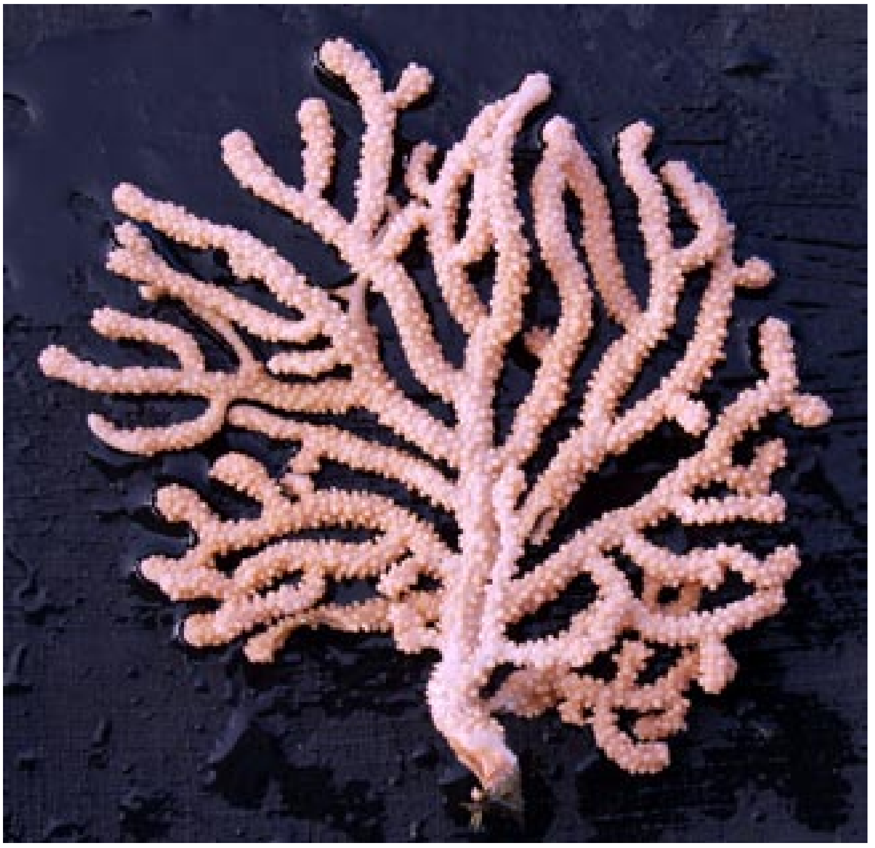


The human population, in evidence on the planet Earth as lights seen from space at night. The magnitude of the human population is one of the primary factors behind abnormalities observed in ecosystems within the biosphere. The human population is itself abnormal in comparison to populations of other comparable species—a primary element of concern in management and usually ignored in conventional approaches (Fowler and Hobbs, 2003) (Photo courtesy of: Marc Imhoff, Christopher Elvidge, Craig Mayhew, and Robert Simmon, NASA/GSFC/NOAA/NGDC).

replaced with effective measures. For example, the limitations of single-species natural resource management are well recognized, as are their resulting failures (Wagner, 1977; Cairns, 1986; Magnuson, 1986; Schaeffer et al., 1988; Ludwig et al., 1993; Safina, 1995; NRC, 1999). More generally, many traditional forms of management, as a whole, have been subject to criticism (Cairns, 1991; Salwasser, 1993; Malone, 1995) or seen as fundamentally flawed and in need of replacement (Norton, 1991; Pickett and Ostfeld, 1995). Perhaps most convincing is the set of problems that confront us as results of past management deficiencies (Fowler and Hobbs, 2002, 2003).

The failures of conventional management have been noted in environmental change which is usually evaluated as degradation (Auerbach, 1981; Silver and DeFries, 1990; Turner et al., 1990; Woodwell, 1990; World Conservation Monitoring Centre, 1992; Meyer and Turner, 1994; Christensen et al., 1996; Vitousek et al., 1997). Such failures have underscored the need to define and devise an effective form of management.

Clearly, there is a need for a managerial approach that would not only apply to multispecies assemblages (Cairns, 1986) but also to ecosystems (Agee and Johnson, 1988; Murawski, 1991; Appolonio, 1994; Moote et al.[2]). Many ecosystems are judged to be in poor health, exemplified by papers dealing with ecosystem health or integrity (Schaeffer et al., 1988; Rapport, 1989). As a result, extensive effort has gone into defining alternative forms of management, especially those that would include ecosystems (Major, 1969; Vallentyne and Hamilton, 1988; Grumbine, 1994; Stanley, 1995; Christensen et al., 1996). Many of these efforts involve attempts to define what has often been called "ecosystem management" (Stanley, 1995; Christensen et al., 1996; Sampson and Knopf, 1996; Jørgensen and Müller, 2000; Moote et al.[2]).



Corals (*Calcigorgia spiculifera* shown here, a cold water coral from Alaska) represent a taxonomic group poorly represented in decision making by managers, either in making decisions about the harvest of fish in associated ecosystems, or in regulating direct effects on species such as corals. Likewise, the symbioses represented by many tropical corals exemplify processes that are poorly represented in what is accounted for by managers (Photo courtesy of: Anne Simpson, NMFS).

Through these efforts, some measure of progress toward including ecosystems in management processes has been realized. Several mandated efforts are underway to do this, and various national and international agencies have adopted policies to require ecosystem approaches to management and to show commitment to the management principles (basic knowledge, understanding, accepted or axiomatic assumptions) that include ecosystems (Munn, 1993; Wallace, 1994; Stanley, 1995; Christensen et al., 1996). The concept of extending management to the ecosystem level has been generally accepted (Pastor, 1995), as is the need to carry out such management.

It is important, however, to avoid mistakes, especially those that would ignore lessons from past experience. One of those lessons involves an error of conventional or traditional management as applied in resource use, business, health, or the world economy. This error is the lack of adequate consideration of complexity and context when dealing with the interconnectedness of the natural world. We should not restrict our focus to ecosystems because that would ignore other important considerations. Thus, it is important to find a form of management that works at numerous levels, neither rejecting single-species approaches (even if, in the end, single-species approaches need to be modified) nor precluding ecosystem approaches. To abandon single-species approaches, while striving to regulate our use of ecosystems, would invite failure.

[2]Moote, M. A., S. Burke, H. J. Cortner, and M. B. Wallace. 1994. Principles of ecosystem management. Unpubl. doc. avail. at Water Resources Research Center, College of Agriculture, Univ. Ariz., 14 p.

This line of logic continues: there are many levels of biological organization. What if we developed a form of management at the ecosystem level and then discovered that it was insufficient because we had neglected consideration of the biosphere, biomes, communities, species, individuals, organs, or cells? Focusing on the ecosystem, to the exclusion of other levels of biological organization, would undoubtedly get us into even larger problems than has conventional focus on single-species management.

In other words, management must be fully systemic; it must account for, and apply to, everything (Lackey, 1995–96). The approach has to be one that, in fact, can provide specific management focus to address the variety of individual issues (e.g. the biomass that we harvest from any individual species, CO_2 production, harvest from ecosystems, or an individual's blood pressure). Very importantly, however, each specific focus must embody an accounting for complexity that does not lose sight of either context (extrinsic factors: e.g. the environment, ecosystems, the biosphere) or content/components (intrinsic factors: e.g. chemical reactions, physiological processes, age structure, individual based dynamics, behavior).

This may sound impossible. Although past experience leads us to believe that a few of the elements we know to be at play in nature can be temporarily ignored, (a common practice in fisheries management since the mid 1950's (Smith, 1994)), achieving a full accounting of complexity is one of the areas where change is necessary. In spite of the inconvenience, we have the responsibility of taking on the challenge—one of the missions of this paper.

Conventional resource management fails to account for many risks and limiting factors. We confine our consideration to factors that we can list or understand well enough to include in models or environmental assessments. For example, Canter (1996) provides instructions for making matrices with marginal lists of factors to consider; but these lists can never be exhaustive owing to the fact that "… there is a selection of data because the total universe, past and present, is not subject to observation …" (Bateson, 1972). In the end, we seek a way that accounts for everything and which will apply to everything (Lackey, 1995–96).

Table 1.—The nine tenets of management documented in this paper. These are presented in greater detail in Appendix 2 and, in the main body of the paper, are developed in regard to the principles on which they are based.

1) Consistent applicability: Management must in every way be applicable at all levels of biological organization, simultaneously and consistently.
2) Accountability for complexity: Management must account for complexity/reality and each element and factor must receive importance in proportion to its relative significance.
3) Guidance from normative patterns: Systems, components of systems, processes, and interactions must fall within their respective normal ranges of natural variation.
4) Risk averse: Management must be precautionary and avoid risk in achieving sustainability.
5) Interdisciplinary: Management must be based on the realm of scientific studies and thereby include all disciplines.
6) Information based: Management must be based upon information, including the products of scientific research, monitoring, and assessment.
7) Measurability: Management must be guided by clearly defined and measurable goals and objectives.
8) Limited control: Management must be carried out in a way that recognizes that control over other systems (e.g. species and ecosystems) is mostly impossible.
9) Human involvement: Management must involve humans and their role as components of at least some natural systems.

As a step forward, we need to recognize past and present shortcomings. As many assert, we must be open to trying entirely different approaches (Santos, 1990; Pfister, 1993; Cortner and Moote, 1994; Mangel et al., 1996; Schramm and Hubert, 1996; NRC, 1999). We may even need an entirely new paradigm upon which to base management (Norton, 1991; Pickett and Ostfeld, 1995). To determine if an approach is acceptable, we must first understand the criteria that have been developed. These criteria are the demands made of management—tenets to which management must adhere. One of the main objectives of this paper is that of reviewing the tenets (requirements, demands, criteria) and the substantiating principles (basic knowledge, understanding, axioms, assumptions) on which they are based. The tenets are products of the history of examining management, with special emphasis on ecosystems, as a step toward encompassing greater complexity. Collectively, these tenets (Table 1, Appendix 2) serve as a prescriptive basis for judging and then accepting or rejecting alternative forms of management (Haeuber and Franklin, 1996). The approaches in use today fail to meet the standards defined by the tenets.

This paper assumes that management must have common elements regardless of the application, question, or system involved. In other words, the principles behind the tenets (especially the 1st and 2nd tenets) are treated axiomatically. There may be more to management that will emerge as its history unfolds and additional needs become acknowledged. However, it is important to recognize progress as we attempt to address the limits and failures of conventional approaches and move forward with systemic management.

The term "systemic management," as the management described herein, might be confused with the approach presented by de Rosnay (1979) and many other presentations of "systemic management" found on the World Wide Web. Systemic management, as defined here, incorporates and expands upon the principles of de Rosnay's systemic approach. In particular, systemic management incorporates the limits of science, human perception(s), and control as a matter of principle. Management as described here removes the option of engineering or designing ecosystems to be the way that we want them (Tenet 8); political, social, religious, economic, or legal special interests are eclipsed by the laws of nature.

There are other differences between systemic management and the systemic approach de Rosnay (1979) describes. To an extent, de Rosnay's systemic approach is a "systems" approach that acknowledges context and environment (e.g. ecosystems interact with each other and occur within the biosphere). However, this is accomplished in the "systemic approach" at the expense of balanced consideration of intrinsic factors, or constituent elements, interactions, and dynamics of subsystems. The main difference is that their actual relative importance is taken into account in systemic management, as developed in this paper, rather than being given importance based on human appraisal and choices—a common problem with much of what is described elsewhere as systemic management.

In the following sections, it may seem like we are trapped or face the impossible as we work through the process of combining the various tenets. Relief is found in the fact that some tenets help solve the dilemmas created by adhering to belief systems behind conventional approaches. The interrelationships among the various tenets will be emphasized in the review of each separate tenet in the next section and again in the discussion. The final sections outline systemic management as a form of management that emerges and is defined by the principles and tenets reviewed below.

The distinctions among the various tenets may seem somewhat artificial, but each one serves to help emphasize a part in the overall process. A great deal of what we have done, have been doing, or do, under the guise of management, has been misguided. Some of what we are doing will have to be abandoned in the change toward adhering to all of the tenets.

Tenets and Principles for Management

The set of tenets for management in Table 1 materialized during about three decades of efforts to define management (Mangel et al., 1996; Christensen et al., 1996; Czech and Krausman, 1997; NMFS, 1999; McCormick, 1999; NRC, 1999; Fowler and Hobbs, 2002; Moote et al.[2]; Appendices 1 and 2). They serve as criteria for management and can be used to evaluate alternative forms of management. They can be used to judge the process but not the results (Appendix 2, Fowler et al., 1999; Fowler and Hobbs, 2002). In this section, the nine tenets are considered as they have been presented in the management literature and as they relate to each other and the principles upon which they are based. The section ends with consideration of other important issues raised in the literature, most of which are components of one or more of the nine tenets chosen for explicit listing.

Evolutionary forces result in differentiation and change such as the loss of flight among various species of birds, exemplified by the Adelie penguin, *Pygoscelis adeliae*. Evolutionary processes in general, are not given the attention in conventional management that is given to factors such as predator/prey interactions. In particular, the evolutionary/genetic effects of human activities on other species play a relatively minor role in the guidance of current management (Photo courtesy of, and copyright by: Larry Hobbs, Inland Whale).

The red salmon (sockeye, *Oncorhynchus nerka*), exhibits a complicated life history involving both fresh and marine waters. Eggs are deposited in fresh water (usually streams), young fish feed in lake systems, and adults return after feeding in the ocean, bringing with them tons of nutrients. The complexity of life history and the flow of nutrients among ecosystems count among factors that contribute to the complexity of importance to management (Photo supplied by, and copyright by: Charles Fowler).

Tenet 1: Management Must In Every Way Be Applicable at All Levels of Biological Organization, Simultaneously and Consistently.

There are several principles behind Tenet 1:

1) In their complexity, biological systems fall into various levels of organization (e.g. individuals, species, ecosystems),
2) Nature is internally consistent because the laws of nature are not broken in, or by, nature, and,
3) In reality everything is interconnected in some way.

Tenet 1 states that management must have applications that consider the hierarchical structure of nature and apply consistently at all levels, including ecosystems. There are various scales of time and space and each must be accounted for in management.

Management cannot be limited to an approach that works only for an individual species, a collection of individual species, or an entire ecosystem. Management applicable to both a group of species and their ecosystem, while an improvement, would still be inadequate because there are more levels of biological organization. For example, each ecosystem is embedded within a matrix of other ecosystems and the regulation of our use of any particular ecosystem must take into account that ecosystem's context (one of the specific requirements of management emphasized by Christensen et al., 1996). Thus, the biosphere is also considered extremely important in achieving sustainability (Myers, 1989; Lubchenco et al., 1991; Fuentes, 1993; Vallentyne, 1993; Huntley et al., 1991). Some refer to management in regard to planet Earth (Santos, 1990) or the ecosphere (Pfister, 1993).

Of course, scale in the levels of biological organization goes the other way as well. There are proteins, cells, embryological processes, individual organisms, and behavior. These are also parts of the complexity for which we must account (Tenet 2). In addition to including such factors in the management of our interaction with ecosystems, our activities at all such levels must also be managed in parallel fashion (i.e. medicine and veterinary care must be conducted in ways that account for species and ecosystems).

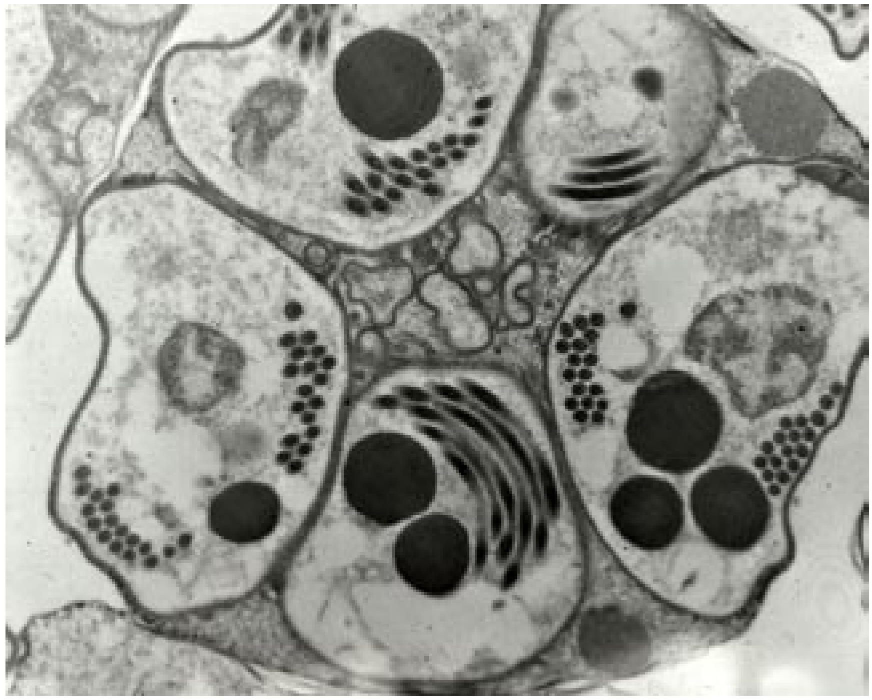
Including ecosystems in the folds of management has been one of the main points made in environmentally oriented management literature of the 1980's and 1990's, and it has been called for repeatedly (Nash, 1991; Mangel et al., 1996; Christensen et al., 1996; NMFS, 1999; NRC, 1999; Moote et al.[2], and references therein). However, it is clear that this is a call for expansion to include, rather than an abandonment of, management involving individual species. Single-species approaches may need to be different, but they cannot be dropped from consideration for they are part of the complexity we must consider (Tenets 1 and 2). Some criticisms of single-species approaches fall just short of calling for their abandonment (Schaeffer et al., 1988). However, most of the literature emphasizes the importance of maintaining a component of management that deals with individual species (Terborgh, 1974; Cairns, 1986; Magnuson, 1986; Ehrlich, 1987; Norton, 1987; Salwasser, 1988; Reed, 1989; Woodruff, 1989; Westman, 1990; Sherman et al., 1991; Franklin, 1993a; Mangel et al., 1996; NRC, 1999) with special importance placed on remembering to include the human species (Tenet 9).

However, consideration of any individual species must include all its interactions with other species (e.g.

coevolutionary interactions, Thompson, 1994) thus returning us to the need to go beyond, without abandoning, consideration of individual species. One of the difficulties of moving toward including ecosystems has been reluctance to change the single-species approaches that have been used for so long (e.g. maximum sustainable yield [MSY], and modifications of such approaches, in the regulation of resource use). The current emphasis on establishing protected areas (e.g. marine reserves) is an attempt to include more factors but in ways that again fail to achieve a full consideration of complexity or consistency with other regulations (e.g. single-species harvest levels in fisheries).

Making management consistent at the various levels of biological organization, and in various scales of time and space, is a serious challenge. The futility of doing so with conventional approaches is relieved by Tenet 8 (we cannot do the impossible). Consider a hypothetical example involving our use of fisheries resources. Managers have a significant problem if one aspect of management (e.g. a single-species approach) results in professional advice to harvest or consume from a particular population of an individual resource species at one rate (say, 100,000 metric tons [t] per year), while a second scheme (e.g. management at the ecosystem level) produces totally different advice (e.g. a total take of only 10,000 t), and a third form of management suggests another strategy (say only 1,000 t per year) in consideration of the biosphere. There is no objective way to chose; each appears appropriate for only one application yet we find ourselves involved in all three simultaneously. It would appear, especially in this hypothetical example, that considering greater complexity leads to greater reductions in resource consumption. Would full consideration of complexity result in advice to consume nothing? Excluding ourselves entirely is not an option (Tenet 9).

Yet there remains the need to manage so that we do not ignore species, ecosystems, or the biosphere. Simultaneously, management must apply consistently at various scales of time and space. There must be a form of management that applies at all levels consistently. Collectively, the hierarchical structure of nature represents one piece of complexity (Tenet 2) that is being emphasized here. Thus, the needed approach also should be one that integrates such considerations (Cairns, 1991) so they apply simultaneously. Otherwise, we have no clear objectives or goals (Tenet 7). If there is inconsistency that spans orders of magnitude (as in the hypothetical fisheries example above), such options provide great latitude to consider anthropocentric issues (e.g. economic, political, social, or religious), thereby assigning them unrealistic importance leading to mistakes.



Pathogens often affect the physiology and behavior of host individuals, making them more prone to predation and thereby influencing their population dynamics. The microsporidian *Thelohania* sp., is shown here exhibiting five of its eight spores in a pansporoblast with lipid droplets (dark circular spots), nuclear bodies, and polar filaments. The microscopic structures, chemistry, and physiology of organisms are part of the complexity important to management (Photo courtesy of: Frank Morado, NMFS).

Such approaches would not consider the complexity of nature (Tenet 2) in a way that avoids placing unrealistic significance on human values and human enterprise. Managers could overemphasize human elements by taking advantage of the leeway among the alternatives. This leeway could come from advice (often conflicting) provided by well meaning experts from different disciplines of science. However, science is limited in this regard. Scientific principles are descriptive, not prescriptive (Santos, 1990), and science, as currently practiced, may never be able to provide consistent advice (Ludwig et al., 1993).

Of the three hypothetical options above for fisheries catches, the 100,000 t option could easily make more sense economically. Short-term solutions often create long-term problems. Mistakes can easily be made by making decisions this way, especially in consideration of short-term issues such as economics, to the exclusion of long-term concerns such as extinction. Such conflicts often become expressed in differing objectives by different management agencies within the same government (Wagner, 1977; NRC, 1999). All things must be considered simultaneously and consistently to avoid a violation of the laws of nature.

The conflicts to be avoided in finding consistency are perhaps nowhere felt more directly than in the dichotomy perceived in the anthropocentric vs. the biocentric interpretations of various management alternatives (Stanley, 1995). The short-term needs of humans must be balanced against the needs of other species (Salwasser et al., 1993), ecosystems, and ultimately, the long-term needs of humans. However, conflict emerges when alternatives are given emphasis based on human value systems (Salwasser et al., 1993; Stanley, 1995; Christensen et al., 1996; Carpenter, 1995; NRC, 1999).

How do we avoid such conflict, especially when it has its roots in the opposing forces of nature (Fowler and Hobbs, 2002)? Every species has needs that are in conflict with those of others. Every species has at least some deleterious effects on its ecosystem. Every species depends on ecosystems to meet its needs. This is all part of the complexity that we have to take into account (Tenet 2).

Despite obvious difficulties, we are not relieved of the need to ensure that any aspect of management is carried out consistently with the others. To complicate things even more, we must also address all issues for which it is possible to undertake management. For example, it is insufficient to manage so that harvests of deer are sustainable. Nor is it enough to regulate the rate at which we introduce species to new environments, or to ensure that the CO_2 that we produce is within sustainable levels; we have to manage all of our activities (Cairns, 1991). We have to manage things such as our consumption of individual resources (e.g. fisheries, forests), our occupation of space, our population size, the areas that we set aside for reserves, the nitrogen that we consume, the energy that we use, and the genetic impacts that we have on other species (Policansky and Magnuson, 1998; NRC, 1996, 1999; Conover and Munch, 2002). The list is virtually endless (Tenet 2).

All elements of management must be consistent. Every form of influence we have at each of the various levels of biological organization must conform with the others. We can't focus on CO_2 production without involving energy consumption, and the management of each one must be consistent with the management of the other. We cannot manage our production of polluting substances and ignore our consumption of resources. They have to be considered collectively and simultaneously (Tenets 2 and 5).

Tenet 2: Management Must Account for Complexity/Reality and Each Element and Factor Must Receive Importance in Proportion to its Relative Significance.

Tenet 2 is based on the principle that reality, or nature, involves complexity (Appendix 3) and diversity of unknown limits. Reality includes all components, with all of their interrelationships, not only among levels of organization (Tenet 1), but also within each level. Each (e.g. component, element, or process) exerts its own level of importance and, in various ways, interacts with, or is connected to, the others. In principle, implementation of this tenet requires full acceptance of human limitations, and the potential of circumventing them through full acceptance of the concept of emergence in which observed patterns are an integration of all the factors contributing to their formation.

Much management literature contains lists of factors to be considered. Owing to human limitation, these lists are restricted to factors regarded as important to account for in making particular management decisions (Appendix 3). The failures of conventional management have often been explained by noting that such lists are incomplete. For example, the failures of single-species management (e.g. fisheries or forests) occur because habitat fragmentation, genetic effects, restructuring of the ecosystem, or the risk of extinction (for any species, including humans, Tenet 9) are not fully considered. It is impossible to consider the unknown. These criticisms lead to attempts to find a way to extend management so that more complexity is embraced .

Including ecosystems is a step toward considering greater complexity in the management process, but it is insufficient (Tenet 1, Christensen et al. 1996). For ecosystems, the elements of complexity include energy flow, coevolutionary dynamics, predator/prey interactions, habitat size, climate, seasonal variation, extinction, and succession—the list is infinite (Appendix 3). Ecosystems represent complexity beyond that of individuals or species because they are inclusive systems comprised of populations (with their individuals) interacting with those of other species and their environments with their own complexities.

The fact that nature is complex has led to axiomatic statements of this fact as one of the principles behind efforts to extend management to include ecosystems (e.g. NRC, 1999; NMFS, 1999). Environmental impact statements and consideration of species for legal protection (e.g. the Endangered Species Act) often involve thinking about such complexity (see Canter (1996), for examples in the application of the National Environmental Policy Act (NEPA)). However, human limitations prevail and such thinking leads to an incomplete listing of the various elements of complexity. Thus, such listings do not lead to advice that, when implemented in management, fully accounts for complexity, or meet the requirements of the other eight tenets considered here.

The populations of the various species around the world (exemplified by the chinstrap penguins, *Pygoscelis antarctica*, shown here) are elements that interact within their ecosystems. These interactions include serving as resources, consuming resources, competing, and having genetic effects through coevolutionary processes—all elements to be taken into account in management (Photo courtesy of, and copyright by: Larry Hobbs, Inland Whale).

Any list of the elements of nature will be incomplete because science involves the ongoing discovery and description of new processes, interrelationships, patterns, species, systems, levels of organization, etc. Hierarchically, there are tens of thousands of chemical compounds, cells, species, communities, ecosystems, and the biosphere with all their interactions and physical processes and forces (e.g. diffusion, adhesion, evaporation, crystallization, gravity, radiation). The various fields of science have resulted in encyclopedic listings and knowledge concerning such factors—all in publications that fill our libraries.

There is no known limit to the detail of such matters, and it is clear that there is still much to be learned. However, many things are probably completely unknowable (Holling, 1993), as exemplified by the fact that we cannot predict the properties of water based on our very detailed understanding of oxygen and hydrogen. Uncertainty (including the unknown) is part of the complexity that we have to deal with (Noss, 1993; Christensen et al., 1996), but it can never be completely eliminated (NRC, 1999). The question to be addressed is: how do we find guidance for, and then conduct management so, the realm of complexity is accounted for with each element being given weight in proportion to its relative importance? How do we account for everything, including the unknowable? We must do so to meet the requirements of both Tenets 1 and 2.

A key factor in getting past what seems like an impossible situation, is the fact that out of complexity, patterns emerge, many of which are unpredictable (Bateson, 1972; Prigogine and Stengers, 1984; Gleick, 1987; Lewin, 1992). This emergence is a general phenomena of complex systems (Lewin, 1992; Kauffman, 1993; Emlen et al., 1998) and not adequately accounted for in current forms of management. The integration of complexity inherent in emergence is central to circumventing the impasses that seem to confront us. The way this works needs further exploration.

Grazing animals, wild (such as the zebra, *Equus burchelli*) or domestic, affect soils. Winds blow dust (including pathogenic organisms) into the atmosphere to be distributed from one continent to another. Rains result in runoff that carries materials to rivers and oceans. These effects exemplify processes that link terrestrial and aquatic systems—links and processes to be accounted for in management (Photo supplied by, and copyright by: Charles Fowler).

How do we proceed with emergence in mind and the fact that Tenet 2 requires that everything (Lackey, 1995–96) has to be taken into account—known (Appendix 3) or unknown (Ehrlich, 1987; Christensen et al., 1996), predictable or unpredictable? Everything plays a different role in nature and each facet is of different importance; nothing can be assumed to be completely negligible. Those things called “butterfly effects” seem small but have incalculable importance (recall the life, war, or kingdom lost for want of a nail), especially collectively and over long time scales (Gleick, 1987; these effects are often referred to as the effects of initial conditions, many of which can be of minuscule importance when considered out of context: Merton, 1936; Bateson, 1979; Koehl, 1989; Pennycuick, 1992; Williams, 1992; Brown et al., 1996). The combination of all of the factors that may seem negligible may outweigh any single factor that we now consider to be the most important. The list of known components and processes in nature continues to grow, and among the unknown may be factors that we will judge to be of extreme importance once they are recognized.

Regardless of the impasse (human limits) reached when we try to think about it, we are left with the need for full consideration of the complexity of reality over the various scales of time, space, and biological organization (the latter emphasized in Tenet 1 and Appendix 3). The context of environmental factors (e.g. ecological complexity) must be accounted for along with the elements of stochasticity and the diversity of processes, mechanics, and dynamics. We are required to proceed with an accounting of the complexity of organizational structure, elements, organs, and physical and chemical processes. How can this be done, given that it is impossible to include everything in our thinking (Agee and Johnson, 1988; Cairns, 1991; Allen and Hoekstra, 1992; Stanley, 1995). The impossibility of

The populations of various species, such as the horned puffin, *Fratercula corniculata*, are monitored as indicators of ecosystem health. Declining trends form a basis for examining the roles humans play in related systems insofar as they contribute to such changes and whether or not our influence (directly on the species or on their ecosystem) is sustainable (Photo supplied by: Charles Fowler, NMFS).

thinking about the unknown is obvious. How do we weigh the unknown relative to the known? Tenet 2 requires that it be done, and, as will be amplified below, emergent patterns provide an integration of such factors. Thus, using empirical examples of sustainability makes it possible owing to their exposure to and emergence from reality (Fowler et al., 1999; Fowler, 2002; Fowler and Hobbs, 2002, Fowler and Crawford, 2004) to provide guidance (Tenet 7).

The need to consider (or account for) complexity falls into at least three categories:

1) Variety in the management questions and issues that call for management action,
2) Complexity as it is involved in the information used to guide action (i.e. complexity involved in setting each specific individual goal and objective, Tenet 7), and
3) Complexity in accounting for the effects of our actions and/or inactions.

We humans (Tenet 9) have influence on the many nonhuman elements of our environment. The combination of kinds of influence and the number of nonhuman elements gives rise to the variety of management questions regarding sustainable influence (category 1). We experience feedback from our influence in a variety of time scales (category 3), and we need guidance that accounts for both the influence and feedback involving all nonhuman factors (category 2). As will be seen below, conventional management falls short in all three categories.

Variety in Management Questions

Attempts to consider complexity are reflected in conventional approaches to management as well as in many extensions to include ecosystems. These are largely superficial steps to make things be what we want them to be, or managing things so that they work the way that we think they should work. However, such attempts have exposed a wide variety of things that are deemed important to do. As a glimpse at complexity, this variety is reflected in much of the literature behind the lists in Appendix 3. For example, it is common to see "ecosystem management" defined as the maintenance of ecosystem integrity (Rapport, 1989; Callicott, 1992; Munn, 1993; Salwasser et al., 1993; Steedman and Haider, 1993; Woodley et al., 1993; Angermeier and Karr, 1994; Grumbine, 1994; Malone, 1995; Christensen et al., 1996; Grumbine, 1997; Moote et al.[2]).

Within the general objective of maintaining ecosystem integrity are the more specific objectives of maintaining viable populations of species, ensuring endangered species recovery, maintaining structural and genetic diversity, restoring ecosystems that have been damaged, and maintaining biological diversity and ecological processes (Clark and Zaunbrecher, 1987; Noss, 1990a; Salwasser et al., 1993; Pickett and Ostfeld, 1995). Other aspects of general ecosystem integrity include primary productivity, nutrient recycling, species richness, population variability, species diversity, species composition by body size, contaminant loads and dynamics, productivity in general, and the portion of species considered to be pests (Rapport, 1989; Munn, 1993; Wood, 1994).

Conventional approaches include the identified need to restore critical ecological components, and structures (Moote et al.[2]), and the regulation of internal ecosystem structure and function, inputs, and outputs (Johnson and Agee, 1988). The attributes of ecosystems are seen as subject to management carried out so as to ensure that desired objectives are achieved (Tenet 7). If we adhere to the combination of Tenets 1, 2, 3, and 7, all such attributes and factors would be dealt with to achieve the desired goals. This would deal with complexity in its full breadth of application (again, breadth that is narrowed significantly by Tenet 8).

In moving beyond single-species approaches to management (those typical of current or traditional resource management), various attempts have been made to develop a method for guiding and regulating the harvest of groups of species in multispecies fisheries (Sissenwine and Daan, 1991). Such attempts are examples of our historical effort to broaden the list of things for which we have management goals. Augmenting such lists is part of our effort to deal with the first of the three categories listed above by posing more management questions. In spite of the known needs, however, current management is largely confined to practices much like those of the past. Many management questions are left largely unaddressed. For example, managing to account for genetic effects of harvesting and to find sustainable harvests from ecosystems has not been possible.

The prairie chicken, *Tympanuchus cupido*, exhibits a mating behavior in which sounds made by the male are important in courtship. Sound is an important factor in the lives of most species, including the mother/pup communication in northern fur seals, and the location of food by many cetaceans. The role of sound in both individual and species-level interactions is an element of ecosystems largely lost in defining the goals of traditional management (Photo courtesy of, and copyright by: Bruce Fowler).

Every management question that we can pose adds to our consideration of complexity (Tenets 1 and 2). Each item of management must be a matter of clear focus and the list of such items must be as exhaustive as possible. The list of what has to be done is itself complex and reflects the complexity of reality, but it does not provide guidance based on anything beyond the need to address every item on the list.

Complexity in Guidance

The response to each individual management question must be guided by a full accounting of complexity. We must fully account for complexity in setting every individual goal (Tenet 7) required of management. In conventional approaches, this is often attempted by constructing synthetic models to provide guiding standards. Including more complexity (components, processes, etc.) in such models represents real, but very limited, progress. To completely account for complexity, we see that we cannot focus so narrowly that we lose sight of the complete array of elements involved. Synthetic models never involve an exhaustive representation of reality. If we were able to construct an adequate model for use in management, it would represent all aspects of complexity.

We cannot manage harvests of resources without considering genetic impacts, indirect effects on other species, coevolutionary interactions, variation in climate, and energy flow in ecosystems. Individuals, behaviors, and pheromone systems must be taken into account as well as the nature of the human species (e.g. our mean adult body size, our trophic level, our metabolic rate, our relationships with other species, etc.). Human systems are complex and are part of the complexity to be considered (Tenet 9).

We must also account for extenuating circumstances at the time management action is taken: environmental conditions, weather, climate, soil or water quality, and season. In addition to present circumstances, there are the historical aspects of complexity, including the historical effects of all environmental factors.

Scavenger species, such as the common snapping turtle, *Chelydra serpentina*, occur in many ecosystems. Their food habits and trophic level are contributions to the structure and function of their ecosystems fully accounted for in systemic management (Photo courtesy of, and copyright by: Bruce Fowler).

Accounting for the Effects of Our Actions and/or Inactions

The "Law of Unintended Consequences" (Tenner, 1996; Rohman, 1999; Gillon, 2000; Lueck, 2000) maintains that, owing to complexity (and emphasizing interconnectedness as part of reality; Christensen et al., 1996), there will always be ripple effects, secondary (and higher order) reactions, side effects, repercussions or domino effects resulting from the actions that we take or choose not to take (Wilcox and Murphy, 1985). Some will be desirable, others will not, and many will remain unknown. The influence that our decisions and actions have on other individuals, species, ecosystems, and the biosphere must be accounted for.

Examples of our influence include the genetic effects we have on other species (Sutherland, 1990; Policansky and Magnuson, 1998; NRC, 1996, 1999; Conover and Munch, 2002). Humans (Tenet 9) constitute part of the environment for these species. At a larger scale, examples are provided by the effects that we have on ecosystems. Many changes have been documented in marine ecosystems (Pauly et al., 1998; Hall, 1999; Kaiser and de Groot, 1999; Jackson et al., 2001; Myers and Worm, 2003). In terrestrial environments, we have seen our actions lead to reduced primary production, loss of nutrients, loss of species diversity, dominance by short-lived opportunistic and often exotic species, increased fluctuations in key populations, retrogression in biotic structure, increased incidence of disease, and other changes (Rapport, 1989; see also Silver and DeFries, 1990; Turner et al., 1990; Woodwell, 1990; World Conservation Monitoring Centre, 1992; Meyer and Turner, 1994; Christensen et al., 1996; Vitousek et al., 1997). Interconnectedness, as part of the complexity of things, guarantees that there will be such influences, many that we cannot measure, and many that affect humans through feedback.

Thus, influence is not restricted to our impacts on our environment; it is not a one-way phenomena. There is always reciprocity to include the feedback to humans from the nonhuman elements of ecosystems that we affect. Owing to interconnectedness, the consequences of our actions include all reactions. The ways such reactions affect us are exemplified by emergent diseases, malnutrition, compromised immune systems, depleted atmospheric ozone, and global warming, often with considerable time lags.

Because our activities have impacts, and result in feedback, such dynamics must be accounted for in management under Tenet 2. This challenge must be met while also adhering to the other tenets, particularly Tenet 3 which requires us to do everything possible to ensure that our actions are not, and do not result in anything, abnormal (Fowler and Hobbs, 2002).

In combining Tenet 1 with Tenet 2, "hierarchy" must be in the mix of considerations to account for complexity. For example, consider the question of how to catch fish. This leads to another question: how many fish to catch. The

Northern fur seals, *Callorhinus ursinus*, exemplify species that move among various ecosystems, spending part of the year in each one. The fact that many species move among ecosystems emphasizes the need for considering combined temporal/spatial scales in decision making (Photo supplied by: Charles Fowler, NMFS).

answer cannot be based only on our needs; it must include consideration of the capacity of fished systems (populations, communities, ecosystems, guilds) to produce fish. Thus, one central question in fisheries management is: how many fish (or how much biomass) should we catch of a particular species?

This leads to further questions such as: how many fish should we catch from an ecosystem, and how many species should we include in the catch? Another question involves what to do to save an endangered species, but this also leads to the question of how many species there should be. For example, what constitutes insufficient diversity, or the converse, excessive diversity?

Also, asking how we should produce food leads to asking how much we should produce. How we feed people then leads to needing to know how many people should there be to feed (and sensitive issues such as limitations on human population). Although extremely challenging, these questions cannot be avoided in meeting the requirements of Tenet 1 and in accounting for complexity needed to adhere to Tenet 2.

Another matter that cannot be left unattended is that of "relative importance." It is always easier to make suggestions than to assign relative importance. It is impossible to realistically and objectively assign relative "importance" to what managers ought to consider in ranking questions, setting goals (Tenet 7), and evaluating the ramifications of our actions.

The limits of science have long been recognized (Bateson, 1972, 1979; Santos, 1990; Peters, 1991; Walters, 1992; McIntyre, 1998; NRC, 1999; Makous, 2000; Schnute and Richards, 2001), largely as a reflection of human limits in general. The ability to rank all factors is beyond the scope of current forms of science (Ludwig et al., 1993). Scientists often debate relative importance, even occasionally find themselves trying to boil things down to a single factor or a very few factors believed to be most important. In the end, Tenets 1 and 2 require that each item be considered in proportion to its relative importance, and none should be neglected. In regulating our harvest of resources, it has historically been assumed that population dynamics weighs heavily among the important issues to consider. The concept of maximum sustainable yield (now completely rejected by some (Stanley, 1995)) was used for years until it was realized that there was more to account for than population dynamics. In this case, we would be hard pressed to place much weight on the effects of moonlight, yet it cannot be ignored because we know it makes a difference in the feeding strategies of many species. Conventional management schemes fail to fully account for individuals within populations, their physiology, their behavior, or their age. Management to adhere to Tenets 1 and 2, on the other hand, would consider all of the factors involved in complexity in a way that each factor is accounted for in proportion to its importance relative to that of all other factors.

Conventional approaches have focused on processes, factors, and elements of recognized primary importance (those seen as first order effects; Smith, 1994 provides an introduction to the history of this thinking in fisheries). We do not deny the existence of second and third order factors, indirect effects, feedback, time lags, and factors for which we have not been able to demonstrate statistically significant influence or importance. However, they are not included in most conventional management schemes, either in proportion to the individual importance of each factor, or, especially, in proportion to their collective importance. Many such things are missing from the models used to consider management options. It is safe to speculate that the collective effects of ignored factors are often (if not always) more important than any one of the individual factors that we now consider directly—the first-order or primary factors. This is part of what the move toward (and now beyond) "ecosystem management" is all about—trying to take into account the cumulative effects of all of the factors that are left unrepresented (or under-represented, or misrepresented) in conventional approaches.

Thus, accounting for complexity in its collective form is a primary challenge (Tenet 5). The unending list of factors, elements, processes, effects, and repercussions that scientists can generate is no more than that—a list, and always an incomplete list (Bateson, 1972). Everything must be accounted for in management and doing so by adding one factor after another in conventional processes is insufficient for deriving goals (clearly impossible using current approaches, if we are to be exhaustive).

How can we treat all factors in combination when providing ourselves with guidance? The factors themselves all have interactions in reality (Costanza et al,. 1992; NMFS, 1999), and these combinations are parts of what must be considered. What tool, model, or process can be used to be sure that the combination is taken into account so that all of complexity is considered with each element considered in proportion to its relative importance? It appears impossible to answer this question using conventional approaches to management. This is a strong argument that such approaches are insufficient/inadequate and need to be replaced rather than extended or perfected. Accounting for, and considering, complexity in its aggregate stands as a primary requirement of Tenet 2. As will be seen ahead, reality (nature) itself becomes the model for considering complexity in management; this is best achieved in adhering to Tenet 3, wherein patterns that are emergent from reality reflect natural limits in ways that automatically provide a complete accounting for complexity.

Tenet 3: Systems, Components of Systems, Processes, and Interactions Must Fall Within Their Respective Normal Ranges of Natural Variation.

The foundation for Tenet 3 is the principle that everything shows variation and this variation is limited (Fowler and Hobbs, 2002, 2003). Both variation and its limits are products of complexity (Fowler and Crawford, 2004), embody complexity, are emergent from complexity, and are part of complexity—all of which is interconnected. Limits include an integration of the risks that contribute to defining observed patterns.

This core tenet of management has been developed in a variety of literature (as reviewed by Fowler and Hobbs, 2002). It requires that any management action must maintain things (e.g. natural systems, their components, processes, and characteristics, etc.) within their normal range of natural variation (Anderson, 1991; Johnston, 1992; Pickett et al., 1992; Fuentes, 1993; Apollonio, 1994; Grumbine, 1994; Wood, 1994; Christensen et al., 1996; Holling and Meffe, 1996; Mangel et al., 1996; NMFS, 1999; Francis et al., 1999; Uhl et al., 2000; Fowler and Hobbs, 2002; Moote et al.[2]). A medical example is the practice of avoiding abnormal body temperatures, blood pressure, or body weight. We have the choice of avoiding abnormal situations that are pathological (Christensen et al. 1996, Fowler and Hobbs, 2002, 2003) or face the consequences (e.g. risks, including extinction, Tenet 4).

One objective of management, then, is to undertake action in every way possible to ensure that systems and processes such as individuals, species, ecosystems, predation, energy flow, and coevolutionary interactions are within (or will return to) their respective normal ranges of natural variation (Rapport et al., 1981; Rapport et al., 1985; Christensen et al., 1996; Holling and Meffe, 1996; Mangel et al., 1996). If we are to avoid the consequences (e.g. risks) of abnormality, any form of management must adhere to this tenet and it must be applied so as to simultaneously adhere to the other eight tenets.

One of the principles behind Tenet 3 is that everything has its limits (Pimentel, 1966; Bateson, 1972; Hyams, 1976; Rapport et al., 1981; Pimm, 1982; Rapport et al., 1985; Salthe, 1985; O'Neill et al., 1986; Slobodkin, 1986; Koestler, 1987; Roughgarden, 1989;

Grime, 1989; Orians, 1990; Anderson, 1991; Meadows et al., 1992; Pickett et al., 1992; McNeill, 1993; Wilber, 1995; Ahl and Allen, 1996; Christensen et al., 1996; Holling and Meffe, 1996; Mangel et al., 1996; NMFS, 1999; Fowler and Hobbs, 2002; Moote et al.[2]). Some limits are obvious: we cannot take more than 100% of the standing stock (plus its production) of a commercially valuable fish population in a commercial harvest; we cannot occupy more than 100% of a continent. Vice versa, human existence would be precluded if we consumed nothing (a violation of Tenet 9).

Other limits are more complicated. Systems, themselves, set limits on their components (Salthe, 1985; O'Neill et al., 1986; Koestler, 1987; Wilber, 1995; Fowler and Hobbs, 2002). A clear example is seen in the fact that one species cannot consist of more than 100% of the biomass in an ecosystem, and one ecosystem cannot comprise more than 100% of the biomass in the biosphere. The balance between the opposing upper and lower limits set on species' populations (the balance commonly referred to as the carrying capacity) are systemic limits set by a combination of factors both intrinsic and extrinsic (which itself involves both top-down and bottom-up factors; Schoener, 1986; May, 1989; Estes, 1996). These limiting factors include such things as diseases, resource availability, population dynamics, metabolic needs (and the related feature of body size), and predation—the list goes on (complexity).

Ecosystems are natural biotic systems and are included among those systems that are expected to fall within their normal range of natural variation through proper management. It is clear that there would be merit in doing whatever possible to ensure that the attributes of ecosystems (e.g. those listed in Appendix 3, such as total biomass, biodiversity, mean trophic level) are not abnormal. It may be difficult to get the normative information to evaluate ecosystems (King, 1993), but acquiring such information would be a significant step toward defining the goals required by Tenet 7. In line with Tenet 2, part of the motivation for identifying the elements of complexity is that of listing the things that would be good or desirable to have fall within their normal range of natural variation (see references in Appendix 3). The elements of complexity include those associated with ecosystems. However, as identified in the discussion regarding Tenet 1, our accounting for complexity must be extended to biomes and the biosphere which are also important to have fall within their normal range of natural variation. Furthermore this must be done in a way that is consistent with ways it is done for medical and veterinary medicine (Rapport, 1992) where abnormal blood pressure, body size, heart rates, food consumption, and body temperatures are recognized as problems. At this point, it is important again to recognize human limits. How do we distinguish the possible from the impossible in deciding what kinds of efforts should be made to ensure that systems, processes, or other factors exhibit characteristics that are within their normal range of natural variation (Tenets 3, 8, and 9).

In part, the principle of avoiding the abnormal involves the concepts of integrity and health. It is possible to argue that a tropical rainforest reduced to one weed and an herbivore is still an ecosystem. However, few would accept it as desirable, or within the normal range of natural variation for such a system in the area where it occurs; most would consider it abnormal, unhealthy, or pathological.

In nearly everyone's mind there are limits to the normal range of natural variation, whether it be for predation rates, population size, extinction rates, diversity, energy flow, or body size. Difficulties emerge in attempts to agree upon the interpretation of such limits, troublesome as they may be to measure. While there is general agreement that limits occur, what those limits are remains debatable. This has resulted in the recognition of Tenet 3 without specification of operational means for implementation (Fowler and Hobbs, 2002). This difficulty is, of course, not an argument against the principle but, rather a challenge to be met in defining a form of management, scientific information, and procedures that will succeed in achieving operational application.

Tenet 4: Management Must Be Precautionary and Avoid Risk in Achieving Sustainability.

The forces of nature pose risk. Among the elements of complexity (including ecosystem complexity) are the variety of risks experienced by individuals, species, and ecosystems. These include those that stem from human influence in our reciprocal interactions with the nonhuman. This principle adds depth to the issue of humans being parts of nature (Tenet 9). Avoiding risk entirely is impossible, and extreme risks (such as human extinction) are undesirable; either one would be in violation of Tenet 3. Management must find the moderation of a workable intermediate or middle way: sustainability.

Sustainability is a primary objective in most management schemes. It appears in the titles of many references cited here and in the literature upon which various advisory groups have based their deliberations (Orians, 1990; Patten, 1991; Naiman, 1992; Aplet et al., 1993; Francis, 1993; Franklin, 1993b; Holling, 1993; Lee, 1993a,b; Mooney and Sala, 1993; National Commission of the Environment Staff, 1993; Noss, 1993; Salwasser, 1993; Salwasser et al., 1993; Maerz, 1994; Wood, 1994; Carpenter, 1995; Interagency Ecosystem Management Task Force, 1995; Malone, 1995; Christensen et al., 1996; Mangel et al., 1996; Schramm and Hubert, 1996; Moote et al.[2]). The thrust of Tenet 4 adheres to the philosophy of maintenance rather than destruction and conservation rather than waste so that humans can have a viable presence (Tenet 9).

Part of the concept of sustainability involves maintaining natural systems within their normal range of natural variation (Tenet 3). It relates to the balance between human needs and the capacity for supportive systems to sustain human needs in mutual and reciprocally sustaining interactions. In principle, the need for achieving sustainability is well accepted even though it is recognized that, as a goal, the concept per se does not meet the demands of Tenet 7 in

The wandering albatross, *Diomedea exulans*, exhibits various behavioral patterns, such as this mating display, as do many species. Behavioral patterns are elements for consideration in the structure and function of ecosystems in the ways they relate to decision making in management (Photo courtesy of, and copyright by: Larry Hobbs, Inland Whale).

being clearly defined, measurable, or quantifiable.

Avoiding risk is closely related to the concept of sustainability and is singled out for consideration in much of the literature on management (Agee and Johnson, 1988; Nash, 1991; Pastor, 1995; Christensen et al., 1996; Mangel et al., 1996; NRC, 1999). Courting risk is the antithesis of sustainability. Risk avoidance is the main theme behind the precautionary approach to management and is often seen as one way of dealing with uncertainty (Peterman and M'Gonigle, 1992; NRC, 1999). One kind of risk to be avoided is the risk inherent in assuming that secondary and higher order effects in the complexity of reality are unimportant or less important than primary factors. Another is that of ignoring such factors because they are difficult to consider, or because they are unknowable. There is inherent risk involved in assuming that the unknown is unimportant. Tenet 4 requires that we account for risks and Tenets 1 and 2 require that we include those that are unknown. Being humanly impossible, this brings us back to the integrative nature of emergent patterns and the continuing theme of using empirical information.

Thus, as with sustainability, avoiding risk can be considered part of, and is certainly related to, Tenet 3. Risk is part of what contributes to observed limits (Fowler and Hobbs, 2002). For example a species that consumes all of its renewable resources will go extinct; therefore, today there are no species that consume all of their resources, and very few (if any) that consume most of their resources. Extinction is a risk to be avoided, as are risks associated with mortality—excessive mortality leads to extinction. These risks, of course, are impossible to avoid entirely and the change that they bring to natural systems is part of their natural dynamics. As in the case of other processes, however, we are bound to try to do what we can to keep them within their normal ranges of natural variation (Tenet 3).

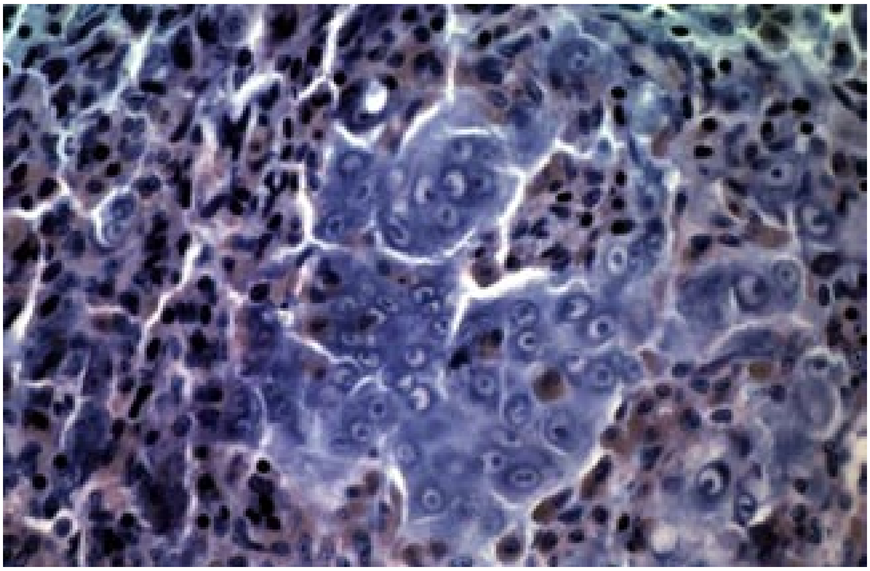
As with anything systemic, however, there is more to risk than extinction or death. There are the risks of anthropogenic effects on other elements of various biotic systems. These influences can result in the affected systems departing from their own normal ranges of natural variation. Enough of these effects can constitute systemic change that results in other risks, such as that of extinction, mortality, starvation, diseases—either for us, as feedback to the human elements in the system, or for other species.

We cannot alter (do not have the control to avoid, Tenet 8) the interconnected nature of systems (Tenet 5) that make such risks and limits a certainty.

Tenet 2 requires that we carry out management so that all risks are considered—something impossible in conventional approaches to management. Risks count among the dynamics involved in the complexity of natural systems. Dealing with risks individually is illogical because mitigating for one risk usually causes others. It is also a practical impossibility because we have no objective way of evaluating the tradeoffs among risks. Nevertheless, Tenet 4 (in combination with Tenets 1 and 2) requires that each has to be dealt with and they have to be dealt with not only collectively but also in proportion to their relative importance. Sustainability is, by definition, not achieved by any form of management that generates more risks than it minimizes (keeping in mind that we cannot completely escape risk).

In either the case of risk or sustainability, the element of temporal scale is fundamental. It is often mentioned that a goal for "ecosystem management" is to provide resources and environments that can sustain the people of future generations (Clark and Zaunbrecher, 1987; Orians, 1990; Huntley et al., 1991; Norton, 1991; Page, 1992; Fuentes, 1993; Lee, 1993a; Salwasser et al., 1993; Christensen et al., 1996; Mangel et al., 1996; NRC, 1999; Moote et al.[2]). This brings up the risk of extinction again, not just the risk of extinction of other species, but the risk of human extinction—another risk to be considered with its corresponding scales of time (Darwin, 1953; Mines, 1971; Lederberg, 1973; Jarvis, 1978; Laughlin and Brady, 1978; Bateson, 1979; Hassan, 1981; Capra, 1982; Jenkins, 1985; Reed, 1989; Tudge, 1989; Eldredge, 1991; Ponting, 1991; Hern, 1993).

How do we find a form of management that can account for each and every risk, consider them as a combination, and account for each one in proportion to its relative importance? How can management do this simultaneously and account for the other principles of management at the same time? This is part of what management must do in order to adhere to all of the tenets and principles of management simultaneously. The answers to these questions continue to develop in an application of Tenet 3, where the integrative nature of empirical information provides a solution to the seeming dead-ends experienced in the thinking behind current forms of management.



Taxon-specific patterns are not typically considered in the elements brought to bear in conventional management. One such pattern is that neoplasms are very rarely noted among arthropods. A neoplasm in red king crab, *Paralithodes camtschaticus*, is shown here as nested epitheliod cells embedded in inflamed cells of surrounding tissues (Photo courtesy of: Frank Morado, NMFS).

Tenet 5: Management Must Be Based on the Realm of Scientific Studies and Thereby Include All Disciplines.

The principle behind Tenet 5 is that nature is a combination of its elements and processes such that they do not operate independently of one another: they are interconnected and consistent (none of the laws of nature are broken). Science needs to present guiding information that reflects this combination, complexity, and consistency. Science can produce a wide variety of information, only some of which is directly relevant to decision making.

The importance of science is stressed in much of the work where the principles of management are developed (e.g. Allen and Hoekstra, 1992; Grumbine, 1994; Wood, 1994; Interagency Ecosystem Management Task Force, 1995; Malone, 1995; Christensen et al., 1996; Mangel et al., 1996). Interdisciplinary approaches are called for repeatedly.

Science plays four roles that vary in the degree to which they are useful in decision making:

1) Discovery of new information (pushing forward the frontiers of knowledge and understanding of complexity; Loucks, 1985),
2) Monitoring systems to provide a basis for evaluation,
3) Measuring systems to determine the nature and limits of their natural variation (Fowler and Hobbs, 2002), and
4) Providing guidance.

The first three roles of science have been or will be addressed in discussions of Tenets 2, 3, 6, and 7. The role of science in validating our concept of complexity was covered above

(Tenet 2). It is important to monitor and evaluate ecosystems, just as it is with all systems, in progressing toward consideration of greater complexity (Steedman and Haider, 1993; Wood, 1994; see also Tenet 6). The measure of natural variation was assumed to be a clear product of science in the treatment of Tenet 3 and is part of the study of complexity as well as monitoring. The measure of variation and its limits will be treated in more detail in consideration of Tenet 7, where we link goals with limits to variation. As such, the first three roles of science will not be given further detailed consideration in regard to Tenet 5. The following is a consideration of the fourth role: providing guidance.

The current role of science stems from the belief that conventional uses of science are adequate (or at least the best we have) to provide guidance (Grumbine, 1994; Wood, 1994; Christensen et al., 1996; Mangel et al., 1996; NRC, 1999). In conventional approaches to management, this role exposes a flaw: science is mostly descriptive, rather than prescriptive (Santos, 1990). In dealing with this flaw, it is very important to note that, in the application of Tenet 5, we are attempting to get to a full consideration of complexity through interdisciplinary approaches (Ray and Grassle, 1991; Allen and Hoekstra, 1992; Grumbine, 1994; Christensen et al., 1996; Mangel et al., 1996). Here is where we run into an insurmountable problem (Ludwig et al., 1993; Salwasser, 1993). Science has great difficulty reassembling the parts of nature that scientists study by combining the information of each of the distinct disciplines (the Humpty Dumpty syndrome: Nixon and Kremer, 1977; Dunstan and Jope, 1993; Regal, 1996; Fowler and Hobbs, 2002). Yet we need a combination of integrative and reductionistic approaches (Ray and Grassle, 1991); we need a way in which reductionistic management questions can be treated in a fully holistic way through or using reductionistic science. It is beyond the scope of science, as conventionally used, to provide realistic guidance that places appropriate importance on each factor in the full suite of elements involved in complexity. We are limited by the fact that complexity, as known through our knowledge of fragmented pieces, cannot be reconstructed in anthropogenic models. The unknown cannot be included in conventional or traditional approaches, regardless of how important it is. We cannot use anthropogenic synthetic models, concepts, theories, or hypotheses to represent full reality; it is impossible (Bateson, 1972, 1979).

Systemic management applies in any habitat, ecosystem, or community, exemplified by marshes, lakes, or ocean basins. The list includes terrestrial systems (species, communities, populations, species, and ecosystems) such as prairies where the black-tailed jack rabbit, *Lepus californicus*, occurs (Photo courtesy of, and copyright by: Bruce Fowler).

Does this mean that science cannot be involved in providing guidance? Guidance, at least of the conventional kind, seems out of the question. However, we are not relieved of the need to find guidance and, if science can lead us to the proper information, it must come from what science can do.

Does guiding information come from the other three roles of science? Indeed it can, and the key to circumventing the limitations of science is integrating Tenet 3 into management to get guidance as directly as possible from reality itself. What we see as the patterns describable by science are emergent from, and account for, complexity based on our understanding of complex systems. As will be seen below, in the process of combining the requirements of Tenet 3 with those of Tenet 7, the third role of science (describing natural variation) solves the problem presented by the reductionistic limits of science (a long-recognized problem, Bateson, 1972; Thorpe, 1974; Bartholomew, 1982; Allen and Starr, 1982; Rosenberg, 1985; Brown, 1994, 1995). Science exposes the source of guiding information, and using that information also achieves the goal of consistency. In many conventional approaches we would attempt to combine related information to be interdisciplinary. To fully account for complexity, all information from all possible disciplines of science would be combined. Because of the unknown, human limitations, and the requirements

The alpine terrain preferred by mountain goats, *Oreamnos americanus*, exemplifies the importance of micro-habitat and the diverse requirements of species in their roles in various ecosystems—all part of the complexity important to management (Photo supplied by, and copyright by: Charles Fowler).

of Tenets 1–3, this is impossible. How do we use the products of science to meet the need for an interdisciplinary approach to account for complexity through scientific efforts? We are back to the promise of the information content and integrative nature of emergent patterns.

It is clear that, despite the inadequacy of the conventional uses of science to represent reality and deal with complexity, the combination of risks (along with the combinations of the other elements of complexity) must be brought to bear in providing guidance for decision-making and management and thus meet the requirements of all nine tenets (Table 1, Appendix 2). The repetitive appearance of the concept of "combinations" above is behind advice to make management interdisciplinary (Ray and Grassle, 1991; Allen and Hoekstra, 1992; Grumbine, 1994; Christensen et al., 1996; Mangel et al., 1996). Achieving an interdisciplinary approach is often subsumed in the concept of holism (Franklin, 1993b; Moote et al.[2]), especially in the move toward including ecosystems in management schemes. It is even more often thought of as a matter of bringing scientists (or others) together in collaborative use of the information that they have to offer.

However, we have already seen that bringing any group of stakeholders together (scientists or otherwise) in an interdisciplinary effort fails to do three things. First, such groups fail to exhaust the list of elements and factors that should be brought to bear (there will always be unknowns and other forms of uncertainty—Tenet 2). Second, it is impossible to find consensus on what the relative importance of various factors might be (and if consensus is found there is no guarantee that the conclusion is not wrong). In conventional or traditional management, factors seen as less important are often relegated to details that will be taken into account later, when we get a better set of information. However, procrastination may be to our peril, and we may never get what we want in traditional approaches. Third, it is impossible to combine the information that science produces (even if we knew all factors to be taken into account and their relative importance) to get a collective consideration of everything (Cairns, 1991). This limitation of science has long been recognized (Bateson, 1972; Thorpe, 1974; Bartholomew, 1982; Allen and Starr, 1982; Rosenberg, 1985; Allen and Hoekstra, 1992; Brown 1994, 1995 (again the Humpty Dumpty syndrome of human limits mentioned above)), but this limitation has not been taken into account in traditional forms of management.

The use of models historically provided hope for progress, but it is now recognized that models make only a

Various species (such as the arctic fox, *Alopex lagopus*, St. Paul Island, Alaska) have isolated populations on islands. Many species, including foxes, have been intentionally introduced to islands resulting in changes in the flora and fauna. Effects of introductions on ecosystems are of note but are not fully considered in conventional management (Photo supplied by: Charles Fowler, NMFS).

small step in the right direction while never reaching the destination. Models help appreciate and understand complexity, but they are not the reality needed (Bateson, 1972). Models perform wonderfully in reinforcing our notion that it is important to consider complexity, and they help us to understand some of things that we would include if we could produce a full representation of reality; however, models (like words) are only superficially representative and not the thing they represent. Our weighting of the relative importance of various factors in our models is often arbitrary compared to the weightings realized in nature. Whether they be statues, photographs, scale models (e.g. airplanes, rivers, or estuaries), computer simulations, equations, or theories and concepts, they do not encompass the full scale of reality (Bateson, 1972; Jørgensen et al., 1999; McIntyre, 1998); just one example of this is the incompleteness of the entire field of mathematics, as represented in Gödel's theorem (Gödel, 1931; Makous, 2000).

Thus, the concept behind interdisciplinary consideration (holism) is, in principle, an essential element of management. It is simply one of several inadequacies of science that we cannot unite the information from the parts that we study in individual scientific disciplines. When it comes to meeting the needs of management in conventional approaches; the unknown is always ignored. However, the need to include an accounting of everything persists as one of the fundamental requirements of the management for which we are striving. Tenet 5 must not be lost in its overlap and interrelationship with other tenets.

Nor should Tenet 5 be ignored because it seems impossible in view of our experience with conventional thinking and management. There is danger in interpreting the partiality of science as a frustration to live with, rather than a basis for, moving to a completely different form of management. If change is needed, we need to know it, accept it, and look for something different. In consideration of Tenets 1 and 2 above, repeated mention was made of the importance of accounting for everything collectively. We may need to change our ways in order to do so. Using the strengths of science in their reductionistic focus on emergent patterns so as to get a direct match between management question and empirical observation is emerging as a way forward (Tenet 6).

Tenet 6: Management Must Be Based Upon Information, Including the Products of Scientific Research, Monitoring, and Assessment.

The principle behind Tenet 6 (Christensen et al., 1996; NRC, 1999) is that information (some of which is accessible to science) is an inherent part of nature. Our measures of processes, relationships, structures, and patterns all provide information that is useful in addressing directly related management questions. Emergent patterns are products of complexity to both account for complexity and represent useful information. Science provides the tools to access information so that it is available for practical application.

The third role of science in management (providing advice: Tenet 5) requires the production of information critical to management. However, science is hampered in providing that information (van Dobben and Lowe-McConnell, 1975; Walters, 1992; Ludwig et al., 1993; Salwasser, 1993; NRC, 1999) because it is impaired by human limitations. In view of the difficulties facing us in meeting the challenges of dealing with complexity, it may be necessary to look to science for information that differs from that currently used (NRC, 1999: "…science … must be tapped to develop new tools for observing and managing…"). We continue to need information; indeed, the lack of information (ignorance) is often found at the roots of mismanagement (Smith, 1977; Carpenter, 1995). This includes the inadequate consideration of things that cannot be known.

If science cannot discover everything, how can the unknown be part of the complexity to be taken into account by using science? Can science be involved in a way that takes advantage of its reductionistic nature and simultaneously account for complexity? Can this be done when monitoring, measuring, and discovering seem to be the only sources of information? Tenet 6 emphasizes the importance of these aspects of science and the progress necessary in adhering to Tenet 3. Documenting, measuring, and describing emergent patterns consonant with management questions becomes an option.

The hookworm (female *Uncinaria lucasi* in this photo) is known to have a direct influence as a parasite on both northern fur seals, *Callorhinus ursinus*, and Steller sea lions, *Eumetopias jubatus*. The tradeoffs among the effects of parasites and competition from other consumers, as well as the synergistic interactions involved, are largely ignored in conventional management, even though they contribute to the patterns observed in ecosystems (Photo courtesy of: Frank Morado, NMFS).

Science is frequently asked to provide monitoring information that can be used in management decisions. Monitoring appears in the titles of many papers (Agee and Johnson, 1988; Johnson and Agee, 1988; Noss, 1990b; Cairns, 1991; Munn, 1993; Noss, 1993; Woodley, 1993; Wood, 1994; Christensen et al., 1996; Grumbine, 1997). Often the need identified is simply for information (usually scientific) or knowledge (Mooney and Sala, 1993; Moote et al.[2]), or occasionally pointing out the inadequacy of what we have (Agee and Johnson, 1988; Cairns, 1991; Huntley et al., 1991; Walters, 1992; Mooney and Sala, 1993; Carpenter, 1995; Naiman et al., 1995; Christensen et al., 1996; NRC, 1999).

How is monitoring useful? Science is crucial for evaluation of progress in achieving management objectives (Tenet 7). How else can we know if the actions that we take in management result in our species, other species, ecosystems, or the biosphere falling within their normal ranges of natural variation (Tenets 3, 7)? We can only know the answers to such questions if we have ways of studying things in regard to their natural variation and ways of comparing current states with standards and goals, especially for things over which we have control (Tenet 8). This concept, for example, is central to the practice of medicine. However, we still need information that can be used to set management goals and objectives (Tenet 7). Can science provide such information through monitoring? Observations provide information on the limits to natural variation of potential use in the implementation of Tenet 3.

While science itself may not suffice to synthesize partially related information effectively (combine, assign relative weights, unite, or put "Humpty Dumpty" back together again, in models, theories, or concepts

(Dunstan and Jope, 1993; Regal, 1996; Fowler and Hobbs, 2002)), scientific information remains of critical value. It is of critical importance that science be used to produce information that can be used in guiding our decision making. We need any information that can be brought to bear in ways that adhere to the other tenets. Such information makes up a key part of the basis for management and, adhering to Tenet 2, management must use such information for each management question before us. This information is produced by monitoring, observing, describing, and documenting—the things that science can do, especially in providing information on the limits to natural variation.

Perhaps of most importance, therefore, is the role of science in defining observed limits to natural variation—discovering, describing, and measuring emergent patterns to adhere to Tenet 3 where the pattern observed is directly consonant with the management question (same dimensions, temporal and spatial scales, and of identical logical types). Insofar as such patterns are emergent from the complexity of reality, they account for complexity (automatically (Fowler and Crawford, 2004), thereby circumventing the reliance on conventional uses of science and their problems).

Each discipline of science can be viewed as involving the proper group of people from whom we should get information regarding the limits to the natural variation of what they study. From such work, especially through comparative studies, the kinds of variation observed in natural systems can be observed, documented, and measured. With this kind of information across time, across space, and over various systems, we begin to appreciate the natural limits to such variation in correlation with environmental circumstances and the qualities of the various species involved—one of the main products of scientific research (exemplified by the growing science of macroecology and the observation of macroecological patterns; Brown, 1995; Gaston and Blackburn, 2000). Identification of the risks of exceeding such limits is also of help, but more in terms of added contributions to our knowledge of the complexity of factors that impose limits than in terms that can directly be brought to bear in management through conventional approaches.

Tenet 7: Management Must Be Guided by Clearly Defined and Measurable Goals and Objectives.

The management of our use of resources relies on directly relevant guiding information in objective metric form that measures the difference between current and desirable circumstances in order to identify problems, guide change, and achieve progress (Christensen et al., 1996; NRC, 1999). These scientific measures of natural systems must be received in useful forms. The value of information to humans is realized only if it can be translated to management objectives to be achieved with directions and actions to be taken. In principle, we can manage only if we know what to do; we cannot manage properly if we do not have goals. We need clear measures of existing problems, especially problems that can be solved through management.

Management is goal driven (Interagency Ecosystem Management Task Force, 1995) and its implementation is aimed at achieving those goals (Salwasser et al., 1993). We must know where we are going and what we want the results to be. We need guidance (Toman, 1993), criteria, standards (Schaeffer and Cox, 1992), benchmarks (Angermeier and Karr, 1994), or landmarks (Ehrenfeld, 1993). Normative or baseline information is critical (Soulé, 1985; Norton, 1987; Agee and Johnson, 1988; Rapport, 1989, 1992; Patten, 1991; Callicott, 1992; Costanza et al., 1992; Page, 1992; Angermeier and Karr, 1994; Davis and Simon, 1994; Maerz, 1994; Christensen et al., 1996).

Without goals, mistakes are virtually guaranteed. Without consistent goals (goals for the variety of management questions that are consistent with each other, Tenet 1), it is easy to under- or over-emphasize human elements (e.g. human institutions, value systems, designs, economic considerations) or human nature. This can lead to serious mistakes. Without objectives, it is easy to encounter unforseen risk; we cannot proceed without knowing where we are going (Tenets 1 and 4). There must be clearly defined goals and objectives (Christensen et al., 1996; NRC, 1999). If these goals are not quantitative, it is difficult to measure progress, to see the change needed in order to achieve success, or to evaluate problems to be solved.

Only by knowing precisely what the objectives are, can science be used to measure progress. Science is critical (Tenet 6) in producing the information to establish goals and objectives at the outset. In this process, science is restricted to observation and measuring variation so that Tenet 3 can be applied. This restriction occurs because (as reviewed above) science cannot combine partially related information from its various disciplines to represent reality in a way that is adequate for management. The interdisciplinary approach is misleading if we try to combine partially or indirectly related information in an attempt to recreate reality. Nevertheless, Tenet 6 (in combination with Tenets 1 and 2) requires that we have an approach that takes account of what we would have if it were possible to reconstruct reality from all the parts to be studied.

While the tenets of management help rule out optional forms of management, we are still without a clear understanding of how management can proceed in meeting them collectively. Does adhering to Tenet 3 provide guidance that satisfies the needs identified in Tenets 1 and 2? How is complexity accounted for by information on, and fitting within, the normal range of natural variation?

Natural patterns are products of, or emergent from, complexity—as an integration of complexity. All factors are involved in this emergence and include those that are currently unknown to us. Natural patterns have their explanation in all of the factors that contributed to their formation. As such, natural patterns are integral. Thus, the use of empirical information on patterns directly related to each management question solves what appears to be an insurmountable problem. (This will be discussed further below, see also: Fowler et al., 1999; Fowler and Hobbs, 2002; Fowler and Crawford, 2004). Complete consonance between guiding information and management issue is achieved only when they are both in the exact same units or dimension.

Management goals must include long-term objectives (Alpert, 1995) and benchmarks relevant to broad spacial scales. It is important to include the elements of complexity (Tenet 2) that involve all temporal and spacial scales. Just as it is important to not abandon single-species considerations, it is also important that we not abandon short time scales in achieving sustainability (Tenet 4); goals should include not only the short-term but also the long-term. This needs to include geological and evolutionary time scales so as to deal with risks (Tenet 4) such as extinction. Short-term goals cannot be forgotten, but focus on them has been part of the pathology identified in traditional forms of management (Holling and Meffe, 1996). Historically, management has focused on short-term issues to the relative exclusion of the long-term. Again, there must be attention paid to the relative importance of long- vs. short-term goals (Tenet 2) so there is consistency (Tenet 1).

Temporal scale is also important in regard to goals and objectives as they relate to levels of biological organization (hierarchical scale). For example, there must be endpoints toward which we want ecosystems to return (Rapport, 1989; Clark et al., 1991; Patten, 1991; Costanza et al., 1992; Davis and Simon, 1994; Schramm and Hubert, 1996), especially so that they fall within the normal ranges of natural variation (Tenet 3) in the various ways they can be measured. These may involve a great deal of time, including evolutionary time scales.

It may seem that the more tenets and principles we consider, the worse the challenges become. Tenet 1 must be adhered to in the process of providing goals—there cannot be conflict between goals for biomass consumption at the single-species level and those at the ecosystem level. Tenet 4 must also be imposed so that our goals clearly avoid risk. Tenet 3 must be followed to allow for the use of information produced by science.

Science can provide information regarding the variation observed for other species, ecosystems, or systems of other hierarchical orders. This pushes the frontiers of management toward greater complexity by allowing for assessment of ecosystems. This information would give us norms and standards against which to evaluate such systems, including human systems (Costanza et al., 1992; Davis and Simon, 1994; Schramm and Hubert, 1996). It would allow for including Tenet 3 in combination with Tenet 7 because we could establish goals in which ecosystems, communities, processes, the biosphere, populations, organs, or individuals would fall within the normal range of natural variation (Callicott, 1992). At least a partial combination of Tenets 2, 3, 5, 6, and 7 is beginning to look possible. However, some aspects of meeting these requirements seem impossible. How do we distinguish the impossible from the possible? Is there a way for the remaining tenets and their associated principals to provide some guidance?

Tenet 8: Management Must Be Carried Out in a Way That Recognizes That Control over Other Systems (e.g. Species and Ecosystems) is Mostly Impossible.

Nature is complex and interconnected. To every action there is a set of reactions. Preventing such reactions is rarely, if ever, under our control, and it is impossible to change the fact that they occur. We cannot avoid or alter the laws of nature, nor can we alter the realities upon which the principles behind the tenets of management are based. There may be some control over the extent of our influence but not the fact that we have influence with all of its repercussions.

It is often said that we cannot manage ecosystems (Lackey, 1995–96; Mangel et al., 1996; Schramm and Hubert, 1996; NRC, 1999), we can only manage people (Cairns, 1991; Christensen et al., 1996; Mangel et al., 1996; NRC, 1999). The wisdom of this statement is seldom integrated into management. Our control over other factors is more limited (Stanley, 1995) than our control over ourselves (Bateson, 1972). Our only option is to manage ourselves (Cairns, 1991; Ehrenfeld, 1993; Christensen et al., 1996; Mangel et al., 1996) knowing that, even in making choices, there are limits to our control.[3] We experience the lack of control in our daily lives; it is part of the exercise of coaching managers of businesses (O'Neil, 1999), and it is true for ecosystems and other species. We can influence other species or ecosystems but we cannot control them. We can facilitate the results that we want in regard to ecosystems, but we cannot make them happen (Francis et al., 1999).

Very importantly, we have no control over the fact that there are secondary (and other higher order) effects of our influence; we cannot avoid the "Law of Unintended Consequences" (Tenner, 1996; Rohman, 1999; Gillon, 2000; Lueck, 2000). This is part of dealing with complexity (Tenets 1 and 2). When we influence another system (e.g. another species), we cannot control the fact that there will be secondary reactions, domino effects, or side effects—including those that come back to haunt us (feedback), often after long delays. We cannot avoid such systemic reactions. Every attempt to mitigate such reactions has its own effects rather than really solving problems. Even controlling ourselves will result in consequences. The game of management is that of choosing self control (intransitive management) so as to do the best job possible to ensure the likelihood of desired outcomes.

Traditional management often embodies the assumption that control over the nonhuman is an option. More generally, it is assumed that we have more control over the other-than-self than is possible. At the species level, this is exemplified by trying to place constraints on populations of other spe-

[3]The serenity prayer applies ("God grant me the serenity to accept the things I cannot change, the courage to change the things I can, and the wisdom to know the difference.").

Physical factors, such as ice in marine systems at high latitudes (here in the Antarctic), are among the elements to be taken into account in management involving ecosystems (Photo courtesy of, and copyright by: Larry Hobbs, Inland Whale).

cies so that they purposely occur outside the normal range of natural variation to increase productivity; these changes are the goal. The MSY concept embodies an intent to maintain resource populations at reduced levels (e.g. one-half of mean normal levels using the logistic model of population dynamics, or 40% typical of fisheries management; Restrepo et al., 1998). As we are seeing, this is no longer an option because it does not account for genetic effects, effects of such reductions on other species, ramifications for the rest of the ecosystem, age structure, extinction, life history strategy, feedback . . . complexity. Humans cannot construct models from selected indirectly related elements to undertake a complete consideration of such complexity.

In spite of the lessons from history, the philosophy behind the MSY approach is carried forward in many attempts to define "ecosystem management." Such control is still seen as an option, perhaps modified somewhat, while focusing on the ground gained in considering complexity by extension of manipulative approaches to ecosystems (e.g. modern agriculture). Management is clearly "human effort to control or direct some entity" (Schramm and Hubert, 1996) and the very term "ecosystem management" connotes such control (as do the terms "resource management," "predator control," and "pest management").

Efforts to avoid this problem have been expressed by using terms such as "ecosystem-based" management (NRC, 1999). The tendency to think in terms of control are clearly identified in the pathology of conventional forms of management by Holling and Meffe (1996). In the end, it is we who are more controlled by the systems upon which we depend, and of which we are a part (Salthe, 1985; O'Neill et al., 1986; Koestler, 1987; Wilber, 1995; Fowler and Hobbs, 2002), than the reverse.

Tenet 8 provides relief from a growing burden; it reduces the realm of options for management considerably. Applying this tenet means that we do not have to try to control any other species, ecosystem, biosphere, community, or landscape to ensure that any of these return to within their normal range of natural variation, or to meet our short-term needs (Tenet 3). We are (or would be) making a mistake to try. The most reasonable management questions are those that are framed in terms of what we can do or change about ourselves (including, now, humans as a species).

When influence on the nonhuman is the issue, the question must always be asked in terms of what is a sustainable level of influence—the influence to which we would confine ourselves. All species have such influence. Importantly, influences are among the things that can be measured and observed to be limited in their variability (i.e. we see balance within the normal ranges of natural variation for such influence, Tenet 3, Fowler and Hobbs 2002, 2003). Relationships are part of complexity, and our relationships with other species, ecosystems, and the biosphere are at stake in appropriate management. Human relationships with the environment need to be within the normal range of natural variation observed in the relationships between other species and the same aspects of their environment.

The issue at stake here involves one of the ways where existing (conventional or traditional) approaches to management get into trouble. The concept of MSY, for example, is based on the premise that we can control a resource population's size so as to elicit a density-dependent response such that increased productivity is made available for human use. The error in this thinking is not in the belief that the density-dependent response will occur, for it usually does. Nor is it erroneous to believe that we can make a change in which the population is reduced (an influence which we and other species have). Such reductions usually occur.

Corals (exemplified by the genus *Anthomastus*) are bottom dwelling organisms representing species that are parts of the marine ecosystems effected by commercial fishing, whether taken directly as target species or subjected to incidental mortality as a result of fishing practices. Both the direct and indirect effects of fishing are to be accounted for in management in order to deal with the full set of factors involved (Photo courtesy of: David Barnard, ADF&G).

Rather, the error is in the belief that such management provokes no other effects (e.g. reactions by other species, altered evolutionary pressures, changes in community composition), or that such effects are of insignificant or negligible importance. We have no control over the occurrence of other effects and they will always occur, many so subtle as to be unmeasurable. However, they remain of collective importance, often in the form of risks that we wish to avoid. To deal with complexity (Tenets 1 and 2), all such effects must be acknowledged and accepted as beyond our control—they cannot be avoided.

The way around this problem is to define our actions as influence rather than control. In this way, control is maximized in terms of regulation of what we are and what we do, not only as individuals but also as a species (i.e. whether it be our population size, consumption of biomass, production of CO_2, or consumption of energy). We then look for information that can be used to guide our influence and make use of science (Tenet 6) to find the information that can be employed in a way that adheres to all of the tenets of management. This helps define the "best available science" as required for decision-making by U.S. law.

Management itself then becomes one of controlling our influence (Cairns, 1991; Christensen et al.,1996; Mangel et al., 1996; NRC, 1999). We regulate our influence, neither setting it at zero (both Tenets 3 and 9 prohibit such extremes) nor promoting too much (not exerting influence above the normal range of natural variation, Tenet 3). Control then is best perceived as an option defined to be more a matter of regulating human influence (intransitive action) than controlling the nonhuman (transitive action). As individuals, we cannot control our species because humans as a species are notoriously resistant to control when it comes to things like self determination, rights to bear children,

The prairie dog, *Cynomys ludovicianus*, is among the many species of the prairies of midwestern North America. It uses oxygen and breathes out carbon dioxide contributing to the composition of the atmosphere that is shared by all species and ecosystems in the biosphere. This kind of world wide interconnectedness is part of what is fully and automatically taken into account in systemic management regardless of the management question being addressed (Photo courtesy of, and copyright by: Bruce Fowler).

and access to resources—all parts of the reality and complexity that must be dealt with in management.

There remains the question of whether or not such control can be realized in a combination of social, religious, legal, international, economic, and governmental action. As a species, the question becomes one of whether or not it is possible for our species to find the means of exerting self control. If we fail to find a means of self control, we have no control over how our unregulated or unconstrained influence will impact other elements of the complex systems in which we find ourselves. There is feedback. There is stochasticity in these processes, and it must be acknowledged and considered in the list of elements that make up reality (Tenet 1). We must expect surprise (Christensen et al., 1996) whether we like it or not. Nevertheless, management would proceed in hopes that the majority of systemic reactions will be in our favor—at least work as well as they appear to have worked for other species (actually, for all other cases represented by the things that we see in their respective normal ranges of natural variation, Tenet 3). The empirical examples of sustainability seem to have worked, and controlling ourselves to mimic such successes is an option.

Tenet 9: Management Must Involve Humans and Their Role as Components of at Least Some Natural Systems.

In principle, humans are subject to the laws of nature, some of which are expressed over evolutionary and geological time scales, as well as various spatial scales, as part of the complexity of reality (Munro and Holdgate, 1991; Mangel et al., 1996; Christensen et al., 1996; NRC, 1999). Part of our existence is that of being a species and knowing that no species is exempt from the laws of nature, including the fact that feedback is always part of the response to our influence. Excluding ourselves entirely (self-imposed extinction) is not a desirable option, even if it is through ignorance.

Removing humans entirely by completely prohibiting anthropogenic influence is not an option for management. To do so would violate both Tenets 3 and 4. We have not achieved sustainability for the human species as an element of biological systems if we argue that we be removed completely. We have also failed if human extinction is a natural consequence of our actions; we are subject to the feedback or reactions of the systems that we influence. Justification for completely removing humans is one of the traps of management when it is focused on ecosystems or the biosphere to the exclusion of considering individual species or individual organisms. Just as the loss of any species at the species level is not an event of sustainability (it is a normal process at the ecosystem and biosphere levels), neither is the removal of humans whether by consequences of our actions (feedback), or as directly intended.

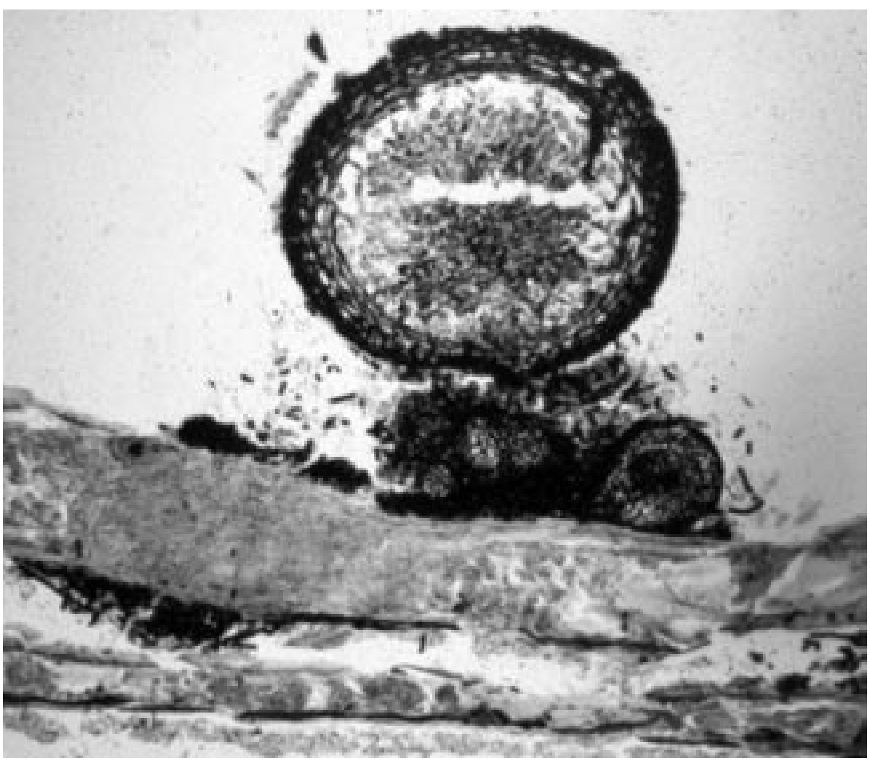
Because extinction of species is a natural process, it is possible to argue that management at the ecosystem level could include the removal of humans; this may be a justified argument for some ecosystems or parts of the world (we have to address the question of how many ecosystems we should occupy). However, even though humans will eventually go extinct, to overtly try to remove humans as a species entirely is not consistent with the idea of sustainability at the species level. One task before us is that of minimizing the risk of our extinction systemically by reducing the contribution of ignorance to such an event as likely as it is to happen regardless of our efforts (Darwin, 1953; Mines, 1971; Lederberg, 1973; Jarvis, 1978; Laughlin and Brady, 1978; Bateson, 1979; Hassan, 1981; Capra, 1982; Jenkins, 1985; Reed, 1989; Tudge, 1989; Eldredge, 1991; Ponting, 1991; Hern, 1993; Boulter, 2002).

Considerable thought has gone into the issue of including humans in ecosystems, landscapes, and the biosphere. Some of this effort was aimed at expanding the complexity we account for in management by including ecosystems; some was to avoid excluding humans, but many references make clear the importance of humans as parts of ecosystems (e.g. Agee and Johnson, 1988; McDonnell and Pickett, 1993; Pfister, 1993; Salwasser et al., 1993; Grizzle, 1994; Interagency Ecosystem Management Task Force, 1995; Malone, 1995; Stanley, 1995; Christensen et al., 1996; Schramm and Hubert, 1996; Grumbine, 1997; McCormick, 1999; NRC, 1999; Moote et al.[2]).

However, questions remain: how can we fit in? Questions for management involve the extent to which humans can be a sustainable part of the biomass of ecosystems, use (and share) the energy passing through ecosystems, exploit other species, or occupy space. Our construction of roads, the size of our villages, and the extent of mining, lumbering, ranching, tourism, introductions of exotic species, fire prevention, and hunting of ungulates must be considered (Patten, 1991). Any such list (e.g. Appendix 3) is the beginning of a list that moves toward complexity (Tenets 1 and 2) but reminds us that we cannot complete the list owing to human limits.

Were we capable of completing the list, however, the list would include, individually and collectively, all influences we have on other systems (such as ecosystems: Franklin, 1993a). Some of these influences (especially the extent of many influences) are now being criticized (Ehrlich, 1987; Rapport, 1989; Ray and Grassle, 1991; Fowler and Hobbs, 2002, 2003) and it is clear that they need to be within the normal range of natural variation (Tenet 3) to be sustainable. Being part of nature means that we affect all natural systems as does every species and are likewise subject to the resultant feedback.

As with single-species approaches to the regulation of our use of natural resources, there are criticisms of our interactions and participation in nature in general; we don't fit in and the lack of fit is exposed in observable abnormalities (Fowler and Hobbs, 2003). The difficulty of a full understanding of humans, especially of the human species as a component of natural systems, comes from a long history of thinking



Fungal communities are recognized as parts of various ecosystems and would be among the factors considered automatically in using systemically emergent patterns for guidance, whether for fisheries, forestry, or agriculture. The fungus in this photo is *Trichomaris invadens* showing the fruiting body external to the host tanner crab, *Chionoecetes bairdi*, a species for which it is suspected that the fungus alters the molting process (Photo courtesy of: Frank Morado, NMFS).

otherwise (Pfister, 1993; NRC, 1999). A good part of the problem is a lack of accounting for complexity and the fact that we are subject to the complicated array or suite of forces that sets limits and poses risks (NRC, 1999; Fowler and Hobbs, 2002). Sustainability is a requirement or goal that applies to humans as well as to other ecosystem components (NRC, 1999).

Questions regarding the extent of sustainable human influence are prevalent in management literature. For continued existence, humans clearly depend on ecosystems for services, materials, energy, and food as does every species. Humans are among the predators within ecosystems (Grizzle, 1994); we consume resources in our harvesting of many other species. The ways we depend on ecosystems includes the production of livestock, vegetable materials, and wildlife for human consumption, water, recreation, minerals, aesthetic experiences, pharmaceuticals, and timber, along with our dependence on ecosystems for normative information and genetic resources (e.g. Lewis, 1969; Christensen et al., 1999). This list is, again, partial but interminable owing to the complexity of reality. We acknowledge our multiple-use relationship with our environment (Salwasser et al., 1993) as part of the fact that we are supported by ecosystems and the biosphere (Baron and Galvin, 1990; Christensen et al., 1996).

We pay lip service to the need to not exceed the limits of such use (Westman, 1990; Salwasser et al., 1993) but fail to prevent such excesses (Fowler and Hobbs, 2003) and fail to treat other aspects of our influence. Complexity also has to do with the effects that we have on other elements of our environment (Ehrlich, 1987; Rapport, 1989; Baron and Galvin, 1990; Ray and Grassle, 1991; Christensen et al., 1996). These effects materialize as we harvest resources, produce carbon dioxide, take up space, interact with other species, produce toxins, channel rivers, build dams and highways (Patten, 1991), or use energy: complexity again. The feedback from these effects is part of the complexity that contributes to risks, constraints, and limits (Fowler and Hobbs, 2002). Our use of ecosystems and the biosphere must count in the kinds of repercussions that are accounted for in management (Christensen et al., 1996; Mangel et al., 1996; NRC, 1999).

Viruses (such as this herpes-like virus in the antennal gland of a red king crab, *Paralithodes camtschaticus*) are known to exist in virtually every ecosystem. However, a full consideration of each and every individual viral "species" is not part of current management processes. A complete foundation for management would not ignore viral particles (exemplified here by the two tiny dark spots at the tip of the arrow), the facility with which they are moved by air, water, or shipping, their influence in systems such as ecosystems, their importance in the dynamics of such systems, or their contributions to emergent patterns in such systems (Photo courtesy of: Frank Morado, NMFS).

Anthropocentric views of management focus on the importance of having options for using things from the systems around us. The basic argument is that humans deserve support and this support is to be guaranteed, insofar as possible, by adhering to Tenet 9. On the other hand biocentric views of management place more importance on the effects that we have in getting this support—the integrity of ecosystems, for example. We cannot be exclusively either anthropocentric or biocentric in our decision making (Terborgh, 1974; Francis, 1993; McDonnell and Pickett, 1993; Salwasser et al., 1993; Stanley, 1995; Christensen et al., 1996; Moote et al.[2]). The tension between anthropocentric and biocentric views (Carpenter, 1995; Stanley, 1995; Christensen et al., 1996) stems from the fact that we need to find a balance between two sets of forces (Christensen et al., 1996).

The experience of conflict in finding a realistic balance results from our attempts to ensure equitable consideration of the two opposing sets as elements of complexity based on conventional approaches. This conflict is parallel to the forces of nature. There are needs and there are effects of getting those needs met. These forces, identified in scientific studies, involve the complexity of the interactions among the various species and their environments. However, we have no way of objectively combining the information from the various disciplines of science that study these factors in order to place realistic relative importance on each of the individual component we are able to bring under consideration. Again, human limits prevent developing and considering a complete list, yet consideration of the complete list is required by Tenet 2. Again, carefully chosen empirical information (Tenet 3) emerges as a way of circumventing the seeming impasse.

Every species places demands on its supporting systems to ensure survival, and each demand produces effects (including feedback that affects the species). There has to be a form of balance between these forces, knowing that for almost all cases it will be anything but a static balance (Christensen et al., 1996). These balances are seen in the resulting emergent patterns observed for other species when the management question involves species-level issues for us humans.

Thus, for humans to be part of systems, we see our way toward defining goals (Tenet 7) regarding how to fit into these systems (e.g. ecosystems, the biosphere, or nature in general) as a species when we use other species as examples of what works. Where do we find scientifically produced information (Tenets 6 and 7) to show us the balance between the forces of nature behind anthropocentric views and the forces behind biocentric views so that we can strive to achieve it? We see the answers to this question embedded in the information (Tenet 6) concerning natural variation and its limits (Tenet 3). This information provides guidance (Tenet 7). An option for management materializes in the combinations of tenets that otherwise seem to define the impossible.

One of the ways that humans must be included in ecosystems is embodied in human action—implementation of management must be done by humans (Agee and Johnson, 1988; McDonnell and Pickett, 1993; Salwasser et al., 1993; Moote et al.[2]). The actions that we take are part of the dynamics of the ecosystems of which we are a part. Many references stress the importance of recognizing the complexity of human action. These involve cultural, social, religious, institutional, psychological, legislative, and political dimensions with different groups of people participating and cooperating (Ovington, 1975; Agee and Johnson, 1988; Lee, 1993b; Grumbine, 1997; Moote et al.[2]).

Various technologies, economics, needs, and values are part of the human system within ecosystems (Schramm and Hubert, 1996) whether it currently fits or not. It is more important to include these elements in working toward objectives (defined by Tenet 3) than in defining them. Scientific disciplines cannot make such decisions (Pfister, 1993); science is only one example of human systems that are limited by the inability to define objective relative importance. However, all human institutions must be involved, whether they be religious, psychological, economic, political, educational, or scientific. Each must cooperate in action to achieve management goals.

There is a distinction between setting and achieving goals. After incorporating Tenets 3 and 8 into management, we are left with human society being responsible for producing the information regarding normal variation (observations through the work of scientists). This defines the science that is most useful in management. This information is then used to set the objectives. That is, we do not set objectives based on anthropogenic activities involving politics, religion, technology, economics, emotions, scientific models, or aesthetics. Then management is taking action. Tenet 7 requires guidance for social decision making and action (Toman, 1993). The models that we are left with are the models that we find in nature to be observed in direct relation to management questions (i.e. of identical units or dimensions, fitting the logical type of the corresponding management question, achieving complete consonance).

In the end, we see that there is more to Tenet 9 than avoiding biocentric values that might preclude human participation in the biosphere. This is more than giving ourselves permission to be part of nature and seeing environmentalism as an effort to make that wrong. It is more than taking responsibility for ensuring that certain ecosystems and the biosphere can support us so that we can be part of nature. It includes responsibility for being sustainable, not expecting such systems to do more than they can, nor expecting support for what we have become or may want to be. Tenet 9 includes the matter of being sustainable. That means change if we are not sustainable now.

Management has to be integrated into the human context (Moote et al.[2]). In combining Tenet 9 with the other tenets, management includes various goals and objectives. These include those realized by allowing other systems to recover so as to support us by being free of abnormal human demands, effects, and impacts. Achieving sustainability means being sustainable, and functioning sustainably, before everything else. Management of ourselves to fit in sustainably takes precedence over the manipulation of nature (Francis, 1993). This is the challenge of management—to be part of the universe by finding our place in it (Swimme and Berry, 1994). Management is the task of finding the balance that makes humans both supported by and supportable by the natural systems on which we depend (Terborgh, 1974; Lee, 1993b).

Other Considerations

The literature on management raises many other considerations. Most fit into, or are parts of, the nine tenets listed in Table 1 and Appendix 2. However, there are several discrete points that deserve mention, at least briefly, some of which could easily be translated to special tenets in their own right. These include the precautionary principle, the burden of proof, and human limitations.

The Precautionary Principle

The precautionary approach is an element of management associated with avoiding risk. The kinds of risk involved are often thought of as either risks associated with statistical uncertainty or risks stemming from the unknown or unknowable.

Polar bears, *Ursus maritimus*, are among the high-latitude species affected by pollutants generated in agricultural activities at lower latitudes. These effects count among those humans have on a global scale along with those we have on individual animals (Photo courtesy of, and copyright by: Larry Hobbs, Inland Whale).

Often, to be precautionary, a safety factor is applied. Safety factors are usually quite arbitrary in being guesses, judgements, products of specialists (either as individuals or groups), or based on synthetic models. The adjustments are subject to bias and human limitations rather than a full or objective consideration of complexity. As argued above, a full consideration of complexity is a logical impossibility in taking such approaches; the unknown cannot be represented objectively in manmade reconstructions based on partial, indirectly related information. By adhering to Tenet 3, however, the risks of uncertainty are confined to measurement error; all other uncertainty, including the unknown are accounted for in the information integrated by natural patterns (Fowler and Crawford, 2004).

Information regarding natural variation is based on our best and most direct perceptions of reality to take advantage of the greatest strength of science. This is its capacity to observe and measure patterns with reductionistic focus where the focus corresponds directly to specific management questions (Fowler et al., 1999; Fowler and Hobbs, 2002). Here, as discussed below, a critical assumption is that we can achieve appropriate alignment between management questions and measurements scientists make. It is assumed that we can define the management question and find the corresponding natural pattern so as to achieve complete consonance between the two. The observations involve patterns measured in units identical to those of the management questions; both are of corresponding dimensions and the same logical type (Bateson, 1972).

Burden of Proof

Related to the precautionary principle is the burden of proof (Wood, 1994; Holling and Meffe, 1996; Mangel et al., 1996; Dayton, 1998). Shifting the burden of proof is so important that it could easily have been included as a separate tenet. Basically, accepting the burden of proof means that we have to prove that what we want, or would like, or think is appropriate or advisable, is in fact a viable option. Thus, if we want

The coyote, *Canis latrans*, exemplifies a species that often coexists with humans. The responses by non-human species to the presence of humans involves a variety of factors, many of which are not accounted for in conventional management but inherent to the complexity accounted for in systemic management (Photo courtesy of, and copyright by: Bruce Fowler).

to reduce a fish population to half of its normal level, we are required to prove that it does not increase or create risk, or does not have abnormal genetic effects on the population or the co-occurring populations of other species.

That we cannot deal with the complexity involved and the impossibility of providing such proof in conventional management, has been a frustration rather than grounds for rejecting such approaches. In applying the nine tenets of management simultaneously, directly related information on empirically observed successes is used to provide proof of what works, tenuous as that information itself may be. In combination with Tenet 3 the burden of proof means that being outside the normal range of natural variation (Tenet 3) is not proof that what we are doing is acceptable; instead, it is to be interpreted more as proof that it is unsustainable. Empirical information from within the normal ranges of natural variation (accounting for correlative patterns) is as close as possible to proven examples of sustainability (Fowler and Hobbs, 2002, 2003).

Human Limitations

Another point chosen for emphasis in the literature involves human limitations. These are manifest in the imperfection of science, our limited knowledge or information, and our incomplete paradigms (Bateson, 1972, 1979; Thorpe, 1974; Holt and Talbot, 1978; Allen and Starr, 1982; Bartholomew, 1982; Rosenberg, 1985; Agee and Johnson, 1988; Allen and Hoekstra, 1992; Brown, 1994, 1995; Christensen et al., 1996; McIntyre, 1998; Jørgensen et al., 1999; Makous, 2000). An attempt to address this issue is seen in the literature that calls for more stakeholder involvement in goal setting (e.g. Slocombe, 1993; Schramm and Hubert, 1996; Ostermeier, 1998; Moote et al.[2]).

However, human limitations prohibit a full consideration of complexity either by individual specialists, or institutional consensus, with one exception. That exception is the matter of agreeing to follow guidance from patterns observed in natural systems as an integration of the complexity we wish to take into account—an integration that is impossible otherwise. The consensus needed is that of accepting Tenet 3 and integrating it into management. Otherwise, we ignore human limitations to assume more control than is possible—a violation of Tenet 8.

The effects of the hierarchical nature of biological systems means that such control is beyond human endeavor (Salthe, 1985; O'Neill et al., 1986; Koestler, 1987; Wilber, 1995; Fowler and Hobbs, 2002). This aspect of complexity has been recognized, and institutional change is usually suggested as a way to achieve effective management (Beissinger, 1990; Myers, 1993; Christensen et al., 1996; Rasmussen, 1996; Moote et al.[2]). Thus, one of the institutional changes needed is a uniform acceptance of Tenet 3.

Humans are real and part of reality, but finite; our concepts, models, science, and representations are always partial. This principle was woven into several of the nine tenets listed above. An additional tenet might require that any successful form of management would account for the fact that we are proceeding with imperfect information, even in our most direct measures of the variability of anything that we subject to scientific study. The points made in the sections above embody the acknowledgment of the limits of science: we can't know everything, models are partial, complexity is beyond perfect representation, scientists cannot recreate reality (in models, concepts, theories, or disciplines—we can only observe it), and we have no way of placing objective relative importance on the parts of reality that we study. This is part of dealing with complexity and forces us to employ empirical information as our best use of science and the attending strengths of its reductionism. Thus, empirical information from other species on their rates of consumption from a resource species (a community, an ecosystem, or the biosphere), production of CO_2, or population size directly address sustainability regarding these specific factors (and simultaneously accounts for all related factors).

In management that implements all nine tenets, the goals, objectives, and standards are observable in natural systems rather than being institutionally derived. However, carrying out management must involve institutions. Guiding information is emergent from complexity—not the deliberations of special interest groups, politicians, scientists, religions, or blue ribbon panels. Nevertheless, the actions to be taken as management have to involve all human institutions (societies, governments, sciences, religions, environmental organizations, etc.). Humans are part of the systems in which we participate (we must consider ourselves that way: Tenet 9), and being and doing what is necessary is the responsibility of everyone, each organization, and every human institution.

Systemic Management

Accepting the tenets of management presented above is not trivial. Any form of management that does not meet all nine is inadequate and probably counterproductive, or even misleading. Yet, the difficulty involved is emphasized by the seeming impossibility of adhering to any two or three of the nine tenets simultaneously. If there are tenets that have been ignored in the compilation of the nine presented here, the challenge is even greater.

One form of relief is found in the reduction of effort, time, and resources expended in the goal setting process when we avoid some of the processes so vulnerable to human limits. Science can be confined to focus more on finding information consonant with specific management questions and less on tangential information. This would involve more attention to problems that can be solved and less on the symptoms of clearly identifiable problems or proving that there are connections. Other institutional efforts can be redirected from goal setting to managing; goals would be set by empirical information provided by the relevant science rather than extensive meetings, debate, and deliberation. Much of what is done in setting goals for current management can be seen as wasteful and could be eliminated. Instead, effort can be diverted to the process of finding relevant management questions and conducting the science to study the directly consonant empirically observed patterns.

Further relief is found in Tenet 8. We do not have to try controlling things that we cannot control. We cannot change (control) the fact that altering the structure of atoms has consequences (some of which we have grown to both respect and abhor for their potential). Chemicals and chemical reactions are part of us and we depend on them; manipulating them can result in significant consequences, only some of which are beneficial. Chemicals and their reactions are the basis for industries involving antibiotics, pesticides, plastics, explosives, energy production, fertilizers, drugs, paints, etc. However, there are always influences and effects beyond what we intend: waste, marine debris, pesticide and antibiotic resistance, CO_2 accumulation, extinction, and pollution (and the reciprocity of feedback to humans; Colborn et al., 1997). Tenet 8 is based on the principle that there will always be ramifications that we do not want or could not foresee when we try to control ecosystems or the biosphere.

We are left with the option of restricting control to ourselves as best we can. Regardless, we cannot avoid unintended consequences and there is rarely full guarantee that we will accomplish the desired results. However, avoiding the abnormal takes advantage of the empirical evidence indicating that the odds of achieving related goals will be in our favor. A huge burden is lifted when we realize that we are advised to restrict control to ourselves; we can stop trying to control (manipulate, design, or engineer) the nonhuman (other species, ecosystems, the environment). This relief involves a combination of both effort and risk; less effort is expended to result in reduced risks. The responsibility and accountability are clearly those of being and doing what we can. This involves the best set of intentions for both humans and other elements in the systems around us.

However, controlling ourselves means that we take the responsibility for correcting the cases where we find ourselves to be abnormal or pathological (outside the normal range of natural variation: Fowler and Hobbs, 2002, 2003). We are confined to this option (Tenet 8). Conventional management has resulted in many of the cases where we find ourselves outside the normal range of natural variation. It is likely that there are cases where conventional management has created more problems than it has solved, especially in the long term, and over broad spatial scales. Many of these problems involve the nonhuman elements in our ecosystems, involve other systems, or are problems that will occur at other times. Because of the interconnected nature of complex systems, however, these problems translate to risks—including such things as the risk of our own extinction (Darwin, 1953; Mines, 1971; Lederberg, 1973; Jarvis, 1978; Laughlin and Brady, 1978; Bateson, 1979; Hassan, 1981; Capra, 1982; Jenkins, 1985; Reed, 1989; Tudge, 1989; Eldredge, 1991; Ponting, 1991; Hern, 1993; Boulter, 2002). Can we adhere to all of the tenets of management collectively by changing to a form of management that solves such problems?

The nine tenets outlined above define systemic management (Fowler and Hobbs, 2002). Conversely, systemic management is a form of management that adheres to all nine tenets. Like all management, it is human action and change, now doing things sustainably, being sustainable, avoiding the abnormal. Initially, it would involve a great deal of change to solve identifiable problems (Fowler et al., 1999; Fowler, 1999; Fowler, 2002; Fowler and Hobbs, 2002, 2003). However, change is a de facto implementation of management; change is a critical part of management (see Christensen et al., 1996, and Moote et al.,[2] regarding commitment to adaptability). In systemic management, change is based on the guidance provided by empirical information regarding the limits of what works. Limits are applicable to each management question that we face (Fowler, 1999; Fowler and Perez, 1999; Fowler et al., 1999; Fowler and Hobbs, 2002, 2003).

Systemic management involves individual people. At the individual level, systemic management is based on information on norms for blood sugar levels, body temperature, heart rate, and blood pressure as commonly seen in medical practice. However, even in examples like these, current management is usually carried out without simultaneous consideration of other levels of biological organization. Full systemic management includes interactions between individual people, other people, species, and ecosystems. Thus, including how individual humans are currently treated is a step toward sustainability (e.g. to avoid the risks of death) by being within (or "controlling" things to be within) the normal range of natural variation for body weight (e.g. Calle et al., 1999), food consumption, and other facets of what we are and do as individuals. However, this treatment is carried out without consideration of questions regarding the limits to which resources can be used to conduct such practices, or ultimate genetic effects. If such issues are ignored, we neglect the hierarchical nature of scale in not only biological complexity, but also in time and space.

The combination of Tenets 1 and 9 require that management have its applications at the level of biological organization involving individual species. Clearly we can go part way in managing our interactions with every other species by fitting within the normal ranges of natural variation for things like competition, predation, and evolutionary/coevolutionary influences. These represent species-by-species applications of systemic management that meet the requirements of the nine tenets. It is important to note that the most important single-species aspect of systemic management is its capacity for a focus on humans and what we can do as a species. In other words, systemic management meets the combination of Tenets 1, 8, and 9 by managing in a way that offers the option of finding sustainability for the human species, and doing so in a way that the sustainability of all other species is simultaneously taken into account.

At the species level, information about things like mean body size, population size, and total consumption rates define the specific dimensions over which the normal range of natural variation among species can be found. At more aggregated levels (ecosystems, communities, landscapes, biosphere), we are restricted to evaluating and assessing because control is out of our reach (Tenet 8). However, there is still a range of variation that is natural and normal—a range that allows for assessment or evaluation. There are patterns and there are limits at all levels (Fowler and Hobbs, 2002). At the levels of ecosystems and the biosphere our management questions are restricted to human influence, even though it is important to continue to ask assessment and monitoring questions (Tenet 6).

Management that applies at the ecosystem level, then, is addressed through questions such as: How many species can we harvest, how much biomass can we take from each ecosystem, and how should we allocate our harvest among selected resource species? What portion of the available resources should we leave for other species and their ecosystems? In systemic management, the answers are based on empirical information (produced by scientific research; e.g. Fowler, 1999; Fowler and Perez, 1999; and Fowler and Hobbs, 2002, 2003 and the references therein) that shows the natural variation that is directly related to (i.e. having the same dimensions as, and being completely consonant with) each corresponding specific question. Our species has influence on such systems, like all species have influence. We have the option of changing ours, but not theirs—even though their influence on the system will change, sometimes as we wish, sometimes in ways that we may dislike. Our goal is to stay within the natural limits observed for the variation among other species, that is, to fit in.

Management based on empirical observation depends on information like that presented in Figures 1–3 (Fowler and Perez, 1999; Fowler, 2002; Fowler and Hobbs, 2002, 2003). Systemic management is the conceptually simple matter of confining humans to positions within such distributions. Thus, central tendencies or statistical confidence limits define measurable goals, standards, or objectives (Tenet 7) when we use adequate and pertinent data sets measured so as to directly correspond to the units and dimensions of the management questions. Owing to our historic influence, current data often fall short of being what we will ultimately need (Fowler, 1999; Fowler et al., 1999). It is not a difficult task to illustrate the goals and objectives, when we have sufficient and appropriate data—data that are often very difficult to obtain.

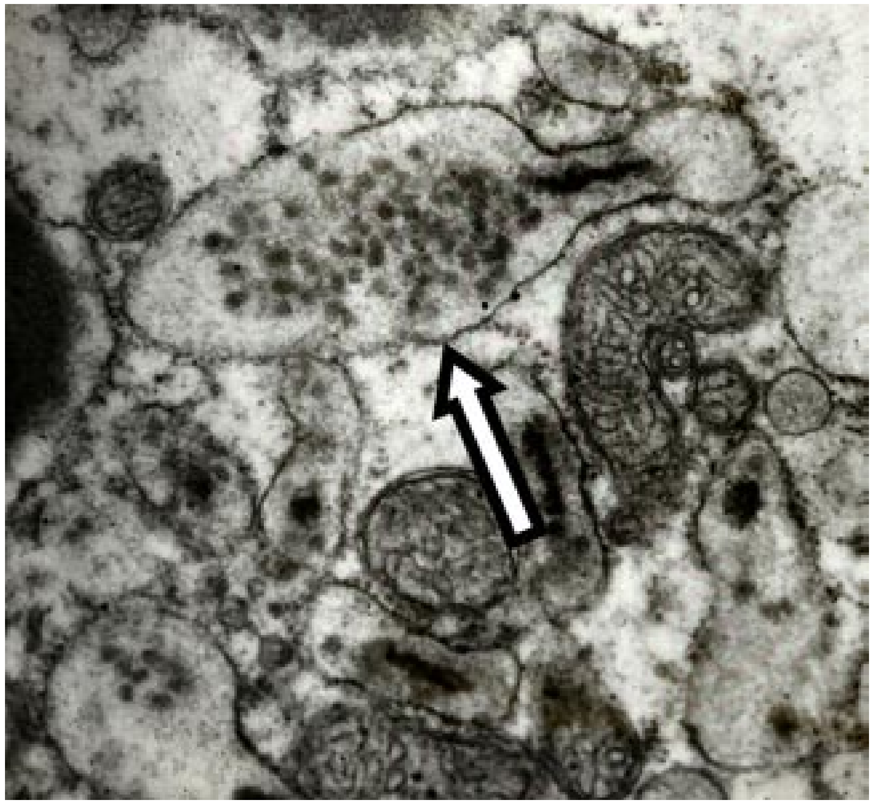
In comparison to this conceptually simple idea, the extremely demanding process of obtaining relevant data is far exceeded in difficulty by the implementation of systemic management. Change is not easy, especially the large changes often shown to be necessary. The implementation of such management may be impossible—beyond the capacity of human skill, will, and commitment. However, attempting such change is part of management (Christensen et al., 1996; Moote et al.[2]) and our responsibility.

At the species level, we are faced by facts similar to those faced by a drug addict, not least of which is the difficulty of change. If it is possible at all, it will have to be carried out by a variety of processes, including (but not confined to) the current processes that we use in management: laws, regulations, education (Agee and Johnson, 1988; Naiman et al., 1995), community participation, public involvement, institutional acceptance and participation (religious, ethnic, economic, and business institutions), and social change. Importantly, it will have to involve individuals as parts of the systems in need of change. Finally, and very importantly, it will take a great deal of time.

Avoiding the abnormal (regaining and staying within normal ranges of natural variation) may seem conceptually simple, even sufficient. However, some positions within the overall range of variation observed represent better options than others. This is because of the fact that everything is interrelated (Christensen et al., 1996; NMFS, 1999; Moote et al.[2]). Clearly, there is a problem to be solved if we, as a species, fall outside the normal range of natural variation observed for all other species. However, it is not necessarily the case that we have maximized our sustainability simply by falling within the normal range of natural variation for all species. Here is where another element of Tenet 9 comes into play.

As a matter of being part of reality, our species has characteristics such as mean body size and metabolic rate. There is more at stake in pointing out such characteristics than questions related to whether or not such characteristics themselves are within the normal range of natural variation. For example, interrelatedness requires that we address questions about normal ranges of natural variation by comparing ourselves to other species with similar body size. Consider an even more specific example: if predation is related to body size, predation should be managed by directly taking body size into account. Thus, it is important to use species (such as marine mammals; Fowler and Hobbs, 2002, 2003) of an average body size similar to that of humans to serve as role models when addressing questions such as how much biomass to harvest from marine resource species, species groups, ecosystems, or the entire marine environment (Fig. 3). Using correlative patterns in this way is another part of the matter of accounting for complexity (Tenet 2).

Systemic management uses empirical information to adhere to all nine tenets above as described and explained in Fowler and Hobbs (2002) (see also Fowler, 1999; Fowler et. al., 1999; Fowler and Perez, 1999). Such management applies broadly and consistently (Tenet 1) at various levels of biological organization (e.g. our species interaction with other species, ecosystems, and the biosphere, Fig. 2; Fowler and Hobbs, 2003). Consistency is achieved when management is based on information from natural systems because the systems from which the guiding information is obtained are themselves internally consistent (Fowler, 1999; Fowler and Perez, 1999; Fowler et al., 1999; Fowler and Hobbs, 2002).



This photo shows a *Chlamydia*-like organism (margin indicated by arrow) inside a cell of its host the Dungeness crab, *Cancer magister*. Reproductive division is shown by the narrow neck containing a division centrum just above a mitochondrion of the host cell. The effects of species such as this, and the roles of microscopic organelles, count among the many unknowns that plague conventional management, but that are fully accounted for in systemic management (Photo courtesy of: Frank Morado, NMFS).

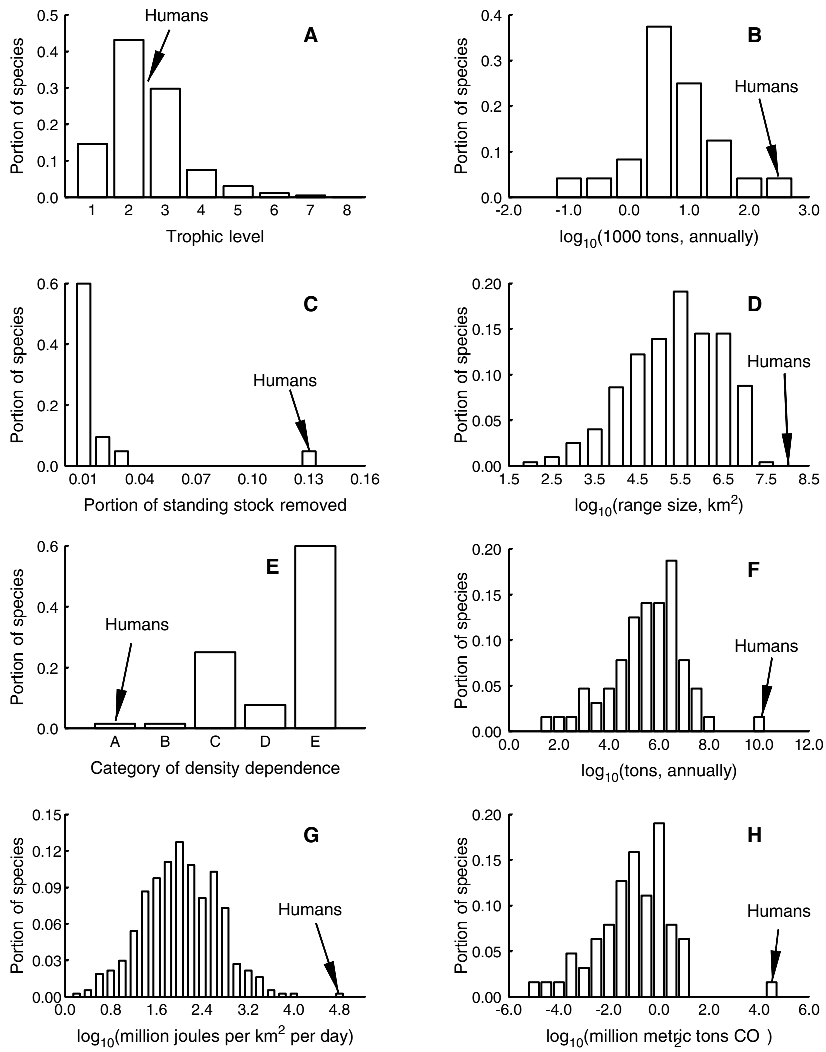


Figure 1.—Frequency distributions among species showing the change needed by humans as management to achieve a position near central tendencies (e.g. means of the distributions, from Fowler and Perez, 1999, where original sources are listed): A) trophic level based on species from 95 insect-dominated food webs; B) consumption of biomass from the Georges Bank ecosystem by 24 species of marine mammals, sea birds, and humans; C) consumption rate of walleye pollock, *Theragra chalcogramma*, by vertebrate predators; D) geographic range size showing humans at 70% of the Earth's non-Antarctic terrestrial surface; E) density dependence for 64 species of invertebrates, fish, birds, and mammals in five statistical categories (from A: positive and statistically significant to E: negative and significant at the 0.05 probability level); F) Total, worldwide, biomass ingested (i.e. not including biomass used for combustion, construction, or other purposes) for humans and 63 species of mammals; G) energy consumption per unit area based on data for 386 species of mammalian primary consumers; H) annual carbon dioxide production.

We adhere to Tenets 1 and 2 automatically and simultaneously because empirical information represent patterns that integrate the full suite of factors we wish to take into account (Fowler and Crawford, 2004). Reality is the source of information so that we are freed of the bulk of limitations and errors inherent in the artificial nature of anthropogenic models. Reality is the model (Ehrenfeld, 1993; Noss, 1993; Angermeier and Karr, 1994; Salzman, 1994; Fowler and Hobbs, 2002) and our errors are largely confined to the ways we measure, observe, and represent natural patterns in dimensions directly pertinent to each management question. However, a full accounting of complexity happens only if all management questions are addressed (our responsibility, Tenet 9), and we can address only those we know of.

Thus, although still confined by human limits, systemic management makes significant strides in minimizing their effects, the Achilles heel of conventional management. Basically, there are four processes where human limits are involved: 1) listing management questions, 2) observing relevant information, 3) setting goals, and 4) carrying out management. Conventional management brings human limits to all four where setting goals, item 3, is particularly vulnerable. In systemic management human limits continue to prevent a full listing of management questions, item 1, and carrying out needed management, item 4, may prove to be beyond reach. However, defining and observing relevant information, item 2, and goal setting, item 3, are relieved of much of the error human limitations bring to conventional management.

Systemic management uses empirical information to account for complexity on all fronts. This happens by virtue of the ways each and every factor plays a role in determining where species occur in the patterns represented by distributions like those of Figures 1 and 2. Each and every factor is represented in proportion to the magnitude of its influence (Fowler, 1999; Fowler and Perez, 1999; Fowler et al., 1999; Fowler and Hobbs, 2002; Fowler and Crawford, 2004). Very importantly, the collection of factors involved is accounted for as a group. The combination is integrated much like Bayesian statistical methods integrate various sets of empirical information in the form of statistics and probability distributions (Fowler, 1999; Fowler and Perez, 1999; Fowler et al., 1999; Fowler and Hobbs, 2002, and see below). Of perhaps most importance, those things unknown to us are included directly. The unknown, in systemic management, hampers our progress primarily in our inability to think of all management questions.

Tenet 3 is a key element in systemic management. Management is achieved in action (such as reducing harvests of fish) to constrain humans so as to fall within the normal range of natural variation, to avoid the abnormal and pathological. This means falling in the vicinity of the central tendencies or within statistical confidence limits (Fowler and Hobbs, 2003) of distributions such as those shown in Figures 1–4. This avoids the collective risks (Tenet 4) that prevent the accumulation of species at the extremes (i.e. beyond the tails of the relevant probability distributions). Again, as with other aspects of complexity (Tenet 2), the collection of risks is accounted for with empirical information and each risk is represented in proportion to its influence—part of its importance.

Information (Tenet 5) is inherent to data such as displayed in Figures 1 and 2, including the information in the genetic code that contributes to what species are and their positions within such distributions (Fowler and MacMahon, 1982; Ehrlich, 1987). Thus, systemic management accounts for time scales (e.g. evolutionary time scales) beyond what are normally considered in current forms of management, which typically focus on a few years at most. Components of complex systems (e.g. species in the biosphere) have survived the test of time, doing the things they do, with the characteristics that they have, to exemplify sustainability as best it can be observed—the sustainability that is the goal of management.

Science is critical in providing the information for the construction of distributions like those shown in Figures 1 and 2 (Fowler and Perez, 1999; Tenet 6). Clear (but temporally and spatially variable) objectives and goals are measurable in the form of the central tendencies of such distributions (Tenet 7, but only when the data are adequate and appropriate by being representative of systems not subject to abnormal human influence; e.g. consumption rates from the biosphere shown in Fig. 3). Stochasticity (as part of reality, Tenet 2) is accounted for in being an inherent part of such distributions. The limits to our control are accounted for in restricting management questions to those regarding human qualities and activities, especially influence and interactions

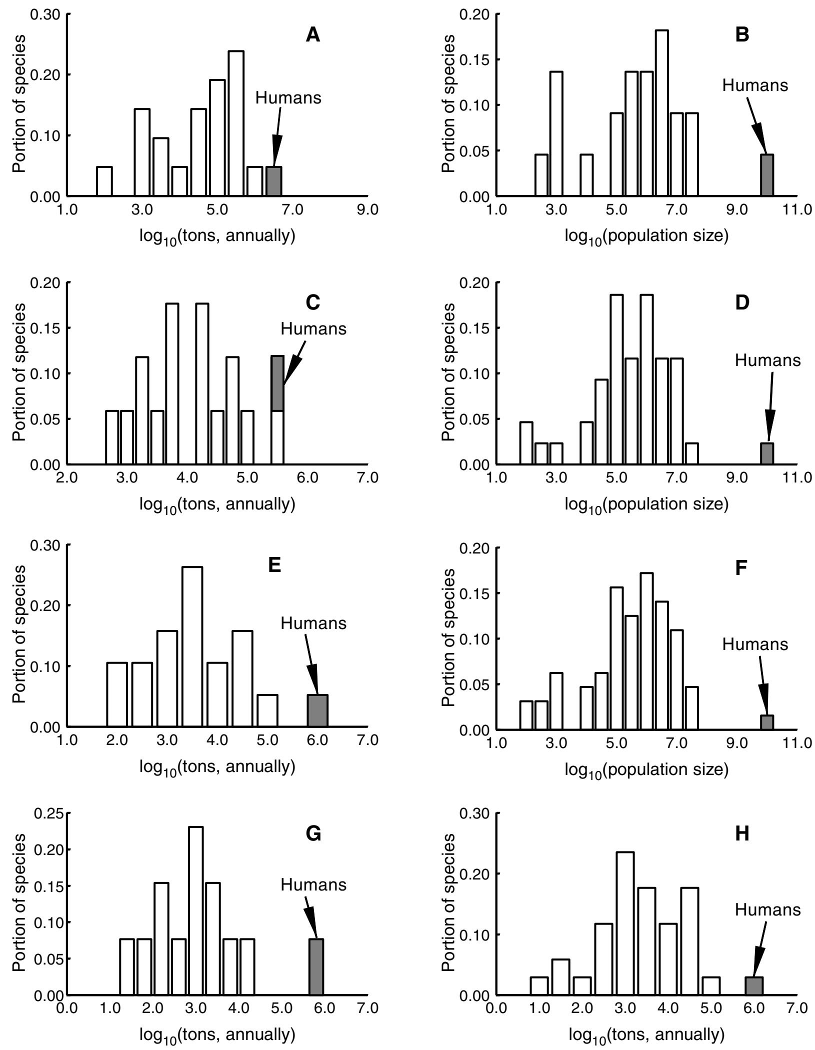


Figure 2.—Species frequency distributions showing the change needed by humans as management to achieve a position near central tendencies (e.g. means of the distributions; from Fowler and Perez, 1999, where original sources are listed): A) Human consumption (harvest) of finfish in the Bering Sea compared to that of various species of marine mammals; B) The total populations of marine mammals in comparison to the total population of humans; C) The consumption of mackerel, herring, sand eel, and hake by marine consumers in the northwest Atlantic compared to consumption (harvest) of the same species by humans (corresponding to the consumption of these species by dogfish; D) The total populations of terrestrial mammals in comparison to the total population of humans; E) The consumption of lantern fish, lightfish, anchovy, and hake by 33 species of marine birds in the ecosystem off the southwest coast of Africa compared to consumption (harvest) of the same species by humans; F) The combination of B and D above to show the human population (5.7 billion); G) The consumption of anchovy by 33 species of marine birds in the ecosystem(s) off the southwest coast of Africa compared to consumption (harvest) by humans; H) The consumption of biomass by 33 species of marine birds in the ecosystem(s) off the southwest coast of Africa compared to consumption (harvest) by humans.

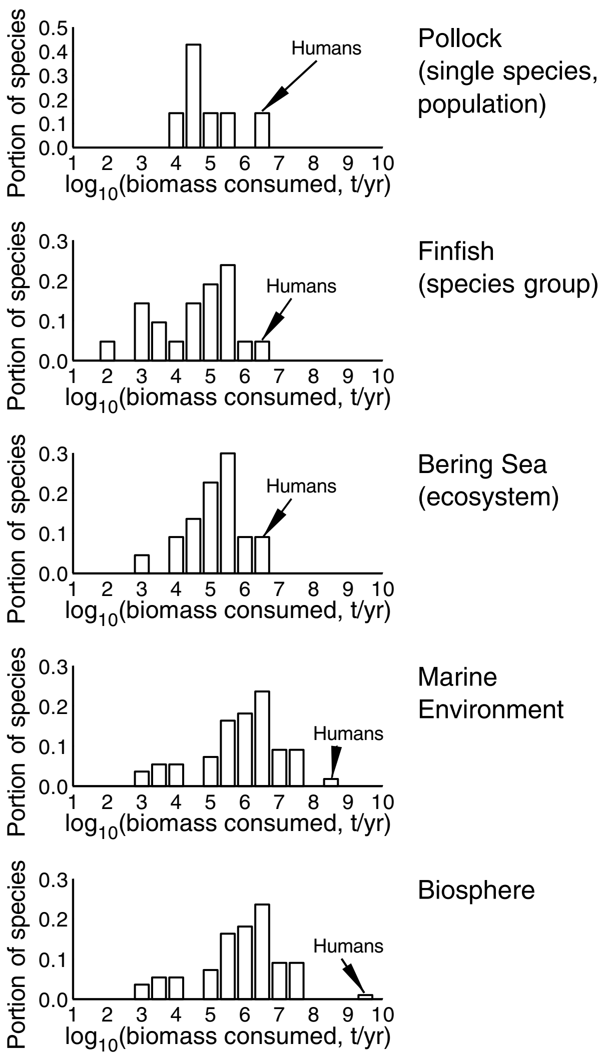


Figure 3.—The frequency distribution of consumption rates for marine mammals showing consumption rates at a variety of levels of biological organization in comparison to the rate at which humans harvest biomass (from Fowler and Perez, 1999, where the original sources are listed). The top panel shows the natural variation in consumption of pollock as observed for six species of marine mammals in the Bering Sea in comparison to recent takes of pollock by commercial fisheries (compare to Fig. 1C). The second panel shows consumption of finfish in the Bering Sea by 20 species of marine mammals compared to human harvests. Total biomass consumption is shown for 20 species of marine mammals in the Bering Sea in the third panel, again compared to the take in commercial fisheries which is predominantly pollock. Total biomass consumption for the entire marine environment is shown in the fourth panel for 55 species of marine mammals, here compared to the take of about 110 million t estimated as the harvest of biomass for human use in the late 1990's. Worldwide consumption of biomass by humans is compared to that of the same 55 species of marine mammals in the bottom panel.

(Tenet 8), whether they be with other species, ecosystems, or the biosphere, and whether for energy consumed, CO_2 produced, genetic effects on other species, or consumption of resources. Such lists are complex. Avoiding the lower limits of many species frequency distributions (e.g. minuscule rates of resource consumption or none at all) guarantees that we are doing what can be done to support human participation in various systems (Tenet 9) rather than removing ourselves entirely.

There may be other principles to which we must adhere, and it is possible that management based on empirical information will not meet all of them. This remains to be seen. At this time, however, systemic management is arguably the most likely way forward. As we examine existing forms of management, we find that each one fails to meet one or more of the criteria substantiated above.

Adoption of the burden of proof is inherent to systemic management. If there is opposition (by political, economic, religious, or another special interest group), those presenting such opposition have the burden of proving that the alternatives they are suggesting will work better than those proven to work in nature. This proof will be difficult, if not impossible, because of the need to establish this proof while simultaneously adhering to all of the tenets (and their foundational principals) laid out above. For example, a fishery operating for 50 years with harvest rates outside the normal range of natural variation of consumption rates by other species has not met the test of sustainability over evolutionary or geological time scales. It will be especially difficult (arguably impossible) to meet the combined requirements of the first five tenets in attempts to prove that anything outside the normal range of natural variation is sustainable. No one would consider trying to prove that a body temperature of 41°C is sustainable for individual humans.

In the quest to consider complexity, it is important to revisit "ecosystem management" in view of the historical attempts to formulate management at this level of biological organization. Ecosystem applications of management based on empirical information (e.g. panel B of Fig. 1 and third panel of Fig. 3) are a crucial part of systemic management. The fact that the scope of applicability of systemic management includes ecosystems is one of the major advantages over conventional approaches. It transcends any individual application to address management questions that heretofore were impossible to tackle, including applications at all of the various levels of biological organization. Now we can address management that also includes the biosphere and the marine environment (Fig. 3).

To help understand systemic management it is useful to note the differences between it and conventional management. Instructive comparisons involve different treatments of reductionism, systems, adaptive management, hierarchical learning, restoration, and several other matters.

Reductionism

To treat the matter of focus, another example of fisheries management helps make the comparison. Francis et al. (1999) point out that, to account for complexity, we would want to set allowable catches to include consideration of the interactions between a target species and their competitors, predators, and prey. The reductionism of conventional approaches would prevent the consideration of predation other than that between a resource species and its prey and predators and maybe a few of the predator/prey interactions of these species and their respective prey and predators. However, the tenets of management require that we also account for predation in general—not just one, two, or several predator/prey pairs, or those directly affecting the resource species, but, instead, all of the predators in the ecosystem and biosphere with all processes involved.

Predation is not the only kind of interactive relationship to consider. We are required to consider not only the competitors that consume the same resources consumed by the target species, but competition in general, including all of the species involved in competition—competition as a process counting among all of the processes involved in ecosystems and the biosphere.

Competition and predation are not alone among the interactive relationships in ecosystems. It is important to account not only for the genetic effects that we have on resource species, but also evolution in general. We need to

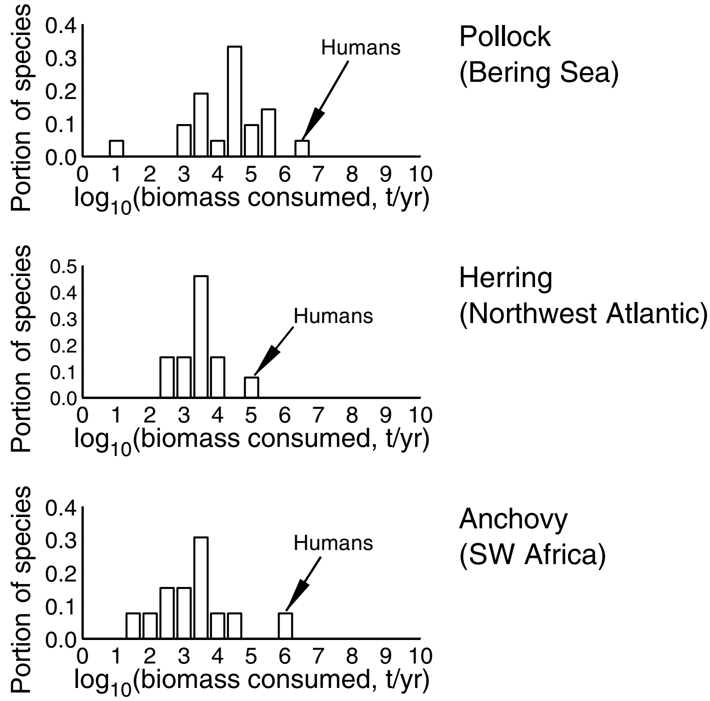


Figure 4.—Species frequency distributions showing data of use in guiding fisheries management in harvests (consumption) of biomass from individual species. The top panel shows 20 species of vertebrate consumers of walleye pollock in the Bering Sea in comparison to recent harvests by commercial fisheries (Livingston, 1993; Fowler et al., 1999). The middle panel show 12 species of vertebrate consumers of herring in the northwest Atlantic (Overholtz et al., 1991; Fowler et al., 1999) and the bottom panel shows 12 species of birds as consumers of anchovy in the Benguelan ecosystems off southwest Africa (Crawford et al., 1991), both in comparison to commercial catches of the corresponding resource species.

consider all species and all interactions to account for complexity. Direct accounting for predation involves the measures of predation rates of all predators that feed on a specific resource species such as pollock, herring, or anchovy. This makes use of directly related information about the predation rates needed to guide fishing; we decide how large the catch should be and what the human predation rate should be to fall within the normal range of natural variation for direct predation on these specific species.

Through systemic management, everything else, including all other predator/prey interactions, is taken into account automatically, especially when human characteristics, such as body size (as discussed above) and environmental circumstances at the time of application (correlative information) are used to refine the choice of natural patterns used as the source of guiding information. This integrative accounting happens by virtue of the fact that the patterns seen in the probability distributions involved in the normal range of natural variation are emergent from the complexity of nature (Fowler and Crawford, 2004). Thus, in our example, all of these predators are exposed to the reality, confined by the reality, and are products of evolution through the effects of the various factors in this reality (Fowler and Hobbs, 2002).

The infinite set of factors involved exhaust the list of those we wish to account for in regulating our catch (Fowler and Crawford, 2004). This includes the prey species on which the target species feed, the coevolutionary interactions of all species involved in the community, physical environmental factors (includ-

Species often depend on (and influence) each other in ways quite distinct from the predator/prey interactions that many ecosystem models attempt to capture. These types of interactions are exemplified by the burrowing owl, *Athene cunicularia*, which nests in holes dug by small mammals. A similar role is played by marine kelp which provides habitat for various life history stages of many species. Symbiotic, commensal, socially facilitated, and other similar interactions are rarely accounted for objectively in current forms of management (Photo courtesy of, and copyright by: Bruce Fowler).

ing all historical events) that present selective forces involved in evolution, and all the rest of complexity for which factors listed in Appendix 3 are just a beginning. The mistakes of building synthetic models to provide advice are avoided because nature is used as the model and accounts fully for complexity. The only models used are the probability distribution representing the pattern directly relevant to each specific management question—more observational than synthetic. The proper reductionistic information is used realistically. Long-term risks are considered in proportion to their relative importance. If there is a risk involving extinction, it is taken into account, whether for other species or our own.

Systems

Another distinction between systemic management and conventional management brings us back to a combination of Tenets 1 and 2. Systemic management is an expansion of systems oriented management, but it is not "systems management." First, the term "systems management" involves the form of words that commonly connote control (in violation of Tenet 8—we cannot manage other systems without the combination of systemic effects, desired or not). Secondly, and not unrelatedly, "systems management" never fully succeeds in dealing with context or environment. Systems always occur within other systems (Wilber, 1995; Christensen et al., 1996) and interact with other systems.

This leads to the hierarchical nature of the resulting levels of organization, and the limiting influence they have (Fowler and Hobbs, 2002)—limits over which our control is limited. Management must apply at all levels, and can only do so through regulation of our influence on systems at each level. An individual engaged in the psychotherapeutic process will affect changes in his or her relationship to family, friends, and/or community. We cannot undertake psychotherapeutic change without concomitant changes in the family or community. Business must be managed in the context of other businesses, questioning whether or not any particular business should exist at all. Fishing must include not only how to fish, but the extent of the area fished, and whether or not a particular species or ecosystem should be fished at all. Questions of urban growth must be extended to management that addresses limits on the number of cities built. Habitat fragmentation brings consideration about the portion of the Earth from which we need to exclude humans.

Adaptive Management

One of the approaches that has been suggested for getting to a workable form of management has been what is called "adaptive management" (Walters, 1986, 1992; Mangel et al., 1996; Grumbine, 1997; Moote et al.[2]). Part of the objective of this process is to gather information toward fulfilment of the requirements of the tenets of management. Beyond this, however, it is important to note that one of the accomplishments of adaptive management is progress in overcoming the limits of science in providing guidance. The basis of adaptive management is a trial-and-error approach in which we learn from experience.

What we have learned in the last century is that while science on its own cannot provide all the guidance that we need, it can help us see reality so that we can understand what to do. The strategy involved in adaptive management is to try various approaches to see if they will work and to learn from the experience. This is the way that systemic management looks at empirical information. Our data on the normal ranges of natural variation are observations of the products of nature's processes, including the trial-and-error process of natural selection. Such data serve as the source of guiding information that represents a tapping of the information content (a cybernetic interpretation, Bateson, 1972) of natural systems through scientific investigation. In other words, distributions such as those shown in Figures 1–4 are integrations of the information presented as the results of nature's Monte Carlo experiments in sustainability that have accumulated over eons of adaptive management experiments conducted in nature, by nature.

Systemic management is action that achieves change to fall within the normal range of natural variation to take account of risks. The accumulation of data on the limits to variation is a learning process that involves both errors (e.g. failures such as extinction) and successes. It is a matter of extending the learning exercise based on experiments conducted by humans (Lee, 1993b) to see the results already accomplished for us by experiments conducted in nature. In this way, we attain a deeper and more profound source of information (Ehrenfeld, 1993; Norton, 1994) that can be used to guide us in meeting the requirements of the nine tenets.

Hierarchical Learning

Individuals learn from personal experience and from each other, regardless of species. Groups learn from group-level experience as well as from other groups. Extending this fractal-like pattern, it may be true that only the human species can consciously learn not only from our own experience as a species but from that of other species. Systemic management is the application of the combination of information from the learning process at each level. This includes the processes of learning to learn and learning to correctly define the link between information and management question to establish objectives.

Individual-level learning through individual-level experience is well recognized (both from personal experience and scientific studies). Beyond personal experience, is the fact that individuals learn from each other, a fact at the heart of our educational system, apprenticeship, and the recognition of role models. Group-level learning through group-level experience is exemplified by "after action review" used in military circles, or the "autopsies/analyses" of past actions conducted by various organizations. Adaptive management (Walters, 1986, 1992; Mangel et al., 1996; Grumbine, 1997; Moote et al.[2]) is the process of group-level learning through designed experiments. Learning by groups from the experience of other groups is exemplified by the benchmarking process in business (Spendolini, 1992; Bogan and English, 1994; Boxwell, 1994; Camp, 1995). The historical study of societies and cultures by archaeologists includes the objective of learning from their successes and failures as groups (e.g. Redman, 1999). Using other species as a source of guidance for human endeavor at the species-level makes use of their lessons as preserved in their genomes.

However, systemic management is not confined to the species level. Such a focus would be a form of reductionism in which we would fail to account for complexity in violation of several of the tenets of management giving rise to systemic management, now to include the matter of learning at, and managing based on the lessons learned at, all levels of hierarchical organization. Lessons learned at one level (e.g. the individual level) are insufficient, and can often be misleading, for guidance at other levels (e.g. the species and the ecosystem).

Ecosystem restoration

The things that humans can do may include ecosystem restoration (Jordan et al., 1987), but, in systemic management, the important aspect of such restoration is that of finding our place in ecosystems. Removing dams and drainage canals is part of restoring the state of ecosystems by reducing the effects of human structures, with the hope of reducing human abnormality. However, restoration must include more such steps to deal with complexity. For ecosystems to be restored, we, the human components, have to fit within the normal range of natural variation for all the other ways all species fit into ecosystems (e.g. population density, consumption rates, occupation of space—the list is virtually endless). We are part of ecosystems (a principle behind Tenet 9), and part of what needs to be restored in ecosystems is their diversity—reduced by any human excesses in which we are abnormal. We must carry out restoration so that it includes groups of ecosystems, landscapes, and the biosphere. Biosphere restoration includes finding our way back to positions within the normal ranges of natural variation in a wide variety of ways (Fig. 1–4)—management is complicated by involving complexity (Tenets 1 and 2). Restoration through systemic management is the intransitive emphasized over the transitive (Tenet 8)—doing and being what humans can do and be (fitting in) to result in a full suite of effects that allow systems around us to do and be what is necessary for both the human and the nonhuman to be both sustaining and sustainable.

Other comparisons

The process of using nature as a guide to integrate complexity has been compared to that of Bayesian statistical integration (Fowler, 1999; Fowler and Perez, 1999; Fowler et al., 1999; Fowler and Hobbs, 2002) wherein complexity is accounted for without theoretical models. Thus, we avoid the limits of science (e.g. limits experienced in the partial models that Bayesian approaches require) because observed probability distributions are the results of an integration of all of the subsumed probability distributions that occur in reality (reality is the model; Fowler and Crawford, 2004). As such, the results are nature's Nash equilibria (Nash, 1950) to account for the hierarchical because they are embedded not only in the various levels of biological organization but in general (Fowler and Hobbs, 2002). Each hierarchical level of organization, along with all of its components, contribute to what we see in a way that is proportional to the relative importance of each element based on an objective and exhaustive accounting for what is involved. As recognized in complex systems science, empirically observed patterns are emergent from complexity to reflect reality, and thus, account for it automatically.

Systemic management, then, is similar to the process of benchmarking in business management (Spendolini, 1992; Bogan and English, 1994; Boxwell, 1994; Camp, 1995), but with a very important difference. It goes beyond the consideration of systems in benchmarking to include contextual scale—questions that would address issues such as whether or not any particular business should be allowed to exist at all (regardless of how well it is run as a system). Benchmarking in business allows for emulation of successful businesses (even if they are competitors), yet is based on considerations restricted to short time scales, measures of economic success, and with minimal, human defined, importance attached to environmental considerations. Effects on other businesses, the environment, risks of human extinction, and human health are some of the other issues that are not given objective and complete consideration. Systemic management, on the other hand, requires that such things be considered and is based on information that automatically takes them into account. It is an emulation of the successes of nature found in the central tendencies of species frequency distributions such as those presented in Figures 1–4. Emulation of nature has been repeatedly suggested for management (Ehrenfeld, 1993; Noss, 1993; Apollonio, 1994; Norton, 1994; Salzman, 1994; Christensen et al., 1996; Benyus, 1997; Fowler and Hobbs, 2002) and is behind the principle involved in Tenet 3. Systemic management is biomimicry (Benyus, 1997) expanded to include all the various levels of biological organization, and specifically species as exemplified in Figures 1–4.

Discussion

The tenets of management specify the qualities of an acceptable form of management and allows for rejecting alternatives. Much management today is based on computer models, theories, concepts, scale models, arguments based on special interests, partial world views, or specific scientific disciplines that produce information often only indirectly related to specific management questions. Guidance, in such approaches, is based on anthropogenic processes that introduce error caused by human limitations. The information used is subject to more human filters than is information directly observed and collected from nature. Scientific observations are descriptive and rarely inform management in the ways they are currently produced and used (Santos, 1990; Salwasser, 1993). To the extent that current approaches do not account for reality, especially the parts of reality that are unknown, they can be discarded as inadequate. Approaches that do not apply at, and account for, all levels of organization (e.g. biological organization from cells to the biosphere) are misleading and probably cause more problems than they solve. Management practices that focus on manipulating pests, species, ecosystems, diseases, and resources ignore the bulk of the ramifications of such actions, especially their impact from our being outside the normal range of natural variation as a species in regard to both the actions taken and the consequences. Such management may meet our short-term needs but does not deal with our long-term needs (generations hundreds or thousands of years from now), and does not adequately consider risks or complexity.

However, having the grounds for rejection does not provide the basis for specifying an acceptable alternative (Haeuber and Franklin, 1996). We cannot afford to discard current management practices until we have an alternative that is a genuine improvement. As described above, systemic management meets the established criteria (unless, of course, one of the requirements had been that it be simple, easy to do, and without significant short-term costs in compensating for errors of the past). Guidance involves the observation of empirical examples of sustainability rather than anthropogenic synthesis of selected indirectly related information. The tenets listed in Table 1 and Appendix 2 define systemic management, but only when all are implemented collectively. Because they define systemic management, it is only natural that it adheres to all of the tenets in their amalgamation. Systemic management is what we have left when other alternatives are rejected. This is parallel to the processes of natural selection resulting in the empirical examples of sustainability as evidence of how to manage. This brings us full circle to seeing management as a matter of ways to "be" (behave, fit in, interact)—the form of management embodied in systemic management.

The importance of institutional and stakeholder involvement in management has been identified and now can be seen to be particularly critical to enabling management carried out as change. Education too, has always been an important element of such processes (Jarvis, 1978; Agee and Johnson, 1988; Aplet et al., 1993; Goudie, 1993; Mazur, 1994; Meffe, 1994; Sieving and Bio Sci 296A, 1994; Swimme and Berry, 1994; Knight and Bates, 1995; Naiman et al., 1995; Christensen et al., 1996). Now the information from species frequency distributions such as those shown in Figures 1–4 represent information that embodies the "inter-species education" suggested by Swimme and Berry (1994). However, education needs to be consistent with reality and is itself complex. To deal with reality our education must include the definition of management that involves being and doing; management is the being and doing behind sustainability and the complicated nature of being and doing what we can. The management—systemic management—is the change necessary to be sustainable and then the maintenance of sustainability achieved. The contribution of education to bringing it about is crucial.

Baseline or normative information from existing systems is a concern that

The thirteen lined ground squirrel, *Spermophilus tridecemlineatus*, is not ordinarily taken into account in fisheries management yet is one species among the many in the biosphere with interactions, however indirectly related, with other species. These would be taken into account in management that is fully systemic, to include regulation of human influences on the biosphere (Photo courtesy of, and copyright by: Bruce Fowler).

must be treated carefully. It is clear that humans have impacted existing systems by being so far outside the normal range of natural variation as to render such systems subject to their own abnormalities (Silver and DeFries, 1990; Turner et al., 1990; Woodwell, 1990; World Conservation Monitoring Centre, 1992; Meyer and Turner, 1994; Christensen et al., 1996; Vitousek et al., 1997; Dayton, 1998). The impact of our population, consumption, CO_2 production, clear cutting, species extinction, use of chemicals, and other factors means that most systems are in a stressed, altered, or abnormal state. As such, these systems are not ideal sources of standards in their current condition. They are not the sources of the relatively unbiased information we would have in the absence of current abnormal human influence (Christensen et al., 1996; Dayton, 1998). Ultimately, what is desired is information from systems that have naturally evolved characteristics (Angermeier and Karr, 1994) wherein we humans are within the normal range of natural variation so that reliable normative information will be available through the data that scientists can collect. As systems change, continued monitoring will identify the changes and the data necessary to guide humans in making responsive change—management to account for current circumstances.

It bears reemphasizing that being within the normal range of natural variation of any particular measure for all species is not enough. It is important to be within the normal range of natural variation as based on measurements from other species similar to humans so that we have accounted for human characteristics such as body size, metabolic category, and trophic level. Of this list, the first two are things that we can change only over evolutionary time scales (possibly impossible to change), while the latter is something that we might choose to change but would probably find unnecessary (Fig. 1) other than during the transition involved in solving other problems. This being the case, if there are management questions for which empirical information is related to any one, all, or any combination of a subset of these three characteristics, the correlative interrelationship would be important in the process of choosing the relevant data for making decisions about objectives based on falling within the normal range of natural variation (Fowler and Perez, 1999; Fowler et al., 1999).

Similarly, correlative information is necessary to take into account extenuating environmental circumstances. Thus, frequency distributions such as shown in Figure 3 would apply only to the climatic conditions under which the data were collected. Adequate data would thus require 1) human influence within normal levels, 2) measurements for species otherwise similar to humans, and 3) circumstances similar to those under which management action is being taken (Fowler et al., 1999; Fowler and Hobbs, 2002).

Terminology can be confusing and the term "systemic management," used for the form of management described above, is one that might lend to confusion involving the "systemic approach" of de Rosnay (1979) and many other presentations of "systemic management" now seen on the World Wide Web. Systemic management, as defined here (and in Fowler and Hobbs, 2002), incorporates the principles of de Rosnay's systemic approach, but expands upon it. Particularly, systemic management includes incorporation of the limits of science, human perception(s), and control as a matter of principle. The systemic management described here removes the prerogative of engineering or designing ecosystems to be the way that we want them (Tenet 8); political, social, religious, economic, or legal special interests are eclipsed by the laws of nature.

There are other differences between systemic management and the systemic approach de Rosnay describes. In at least some ways, de Rosnay's systemic approach is a "systems" approach that acknowledges context and environment (e.g. ecosystems interact with each other and occur within the biosphere). However, this is accomplished in the "systemic approach" at the expense of balanced consideration of intrinsic factors, or constituent elements, interactions, and dynamics of subsystems. The main difference here is that their actual relative importance is taken into account in systemic management rather than being given importance based on human appraisal and choices—a common problem with much of what is described elsewhere as systemic management.

One of the things that has confronted most of the panels and authors over the history of developing "ecosystem management" is the misleading nature of this form of words. Aside from involving a noun modifier to shorten the term (presumably from something like "management at the ecosystem level"), the term "ecosystem management" connotes control over ecosystems. The National Research Council (NRC, 1999) chose to address this matter by using the term "ecosystem-based management." The confusion is that of the distinction between the transitive and the intransitive form of the verb "to manage."

Much of the history of management involves use of the transitive form, implying that we are making the object of our management the wildlife (as in wildlife management, e.g. "Journal of Wildlife Management"), predator-prey interactions (Orians, 1990), the environment (Costanza et al., 1992; Interagency Ecosystem Management Task Force, 1995; Malone, 1995; and the journal Environmental Management), planet Earth (Santos, 1990), and pests (as in pest management). Now we have a literature replete with the term "ecosystem management" (e.g. Ovington, 1975; Johnson and Agee, 1988; Interagency Ecosystem Management Task Force, 1995; Malone, 1995; Naiman et al., 1995; Christensen et al., 1996; Sampson and Knopf, 1996, and many other references used in this paper); the term often appears in the titles of papers dealing with management at the ecosystem level.

Words, meanings, and communication are important in understanding systemic management. Tenet 8 requires that we be very careful in what we mean with the words that we use. As stated by Norton (1991), "Adopting a new paradigm represents a more radical departure; it is to interpret the world in a new format, a format that is given shape and structure by the development of new concepts and a vocabulary to express them." The shift involved in getting to systemic management is one toward direct management of ourselves, thus emphasizing the intransitive form of the verb "to manage." To accomplish progress in this shift, other terms have been used. Salwasser et al. (1993) use the term "ecosystem perspective," and Vallentyne and Hamilton (1988) refer to the management of human interaction, uses and abuses of resources. In the end, it is the fisheries that we manage—not the fish, not the ecosystem from which the fish are extracted, nor the biosphere. In systemic management, management at the ecosystem level is regulation of our interactions, relationships, and influences on such systems.

It is important to distinguish reductionism in science and management. Every question has a specific reductionistic focus. We have to be able to reduce management questions to specifics in order to make decisions and carry out management. Each management question must be framed in very specific units and dimensions. If it were not for the capacity of science to focus on specific measures of variation (Tenet 3), we would be left without the information that science can produce. Management would be without the information it needs to meet the nine tenets substantiated above. The limits of science in its reductionism are reflected more in the inability to recombine information than in the capacity to observe objectively. The door is open for taking advantage of the fact that science provides the most objective means that we have for tapping the information regarding the parts of complexity so that patterns can represent complexity (thus, fully accounting for complexity–reality)—each part being a product of complexity (emergent).

We have not completed the task of dealing with the matter of relative importance. Exercising systemic management is something that clearly cannot accomplish desired objectives overnight. Where do we start? How long do we have? What objectives are most important to achieve first? What are our priorities (Schramm and Hubert, 1996)? If we were to find ourselves within the normal range of natural variation for everything that we can think of to measure, maybe there would be no problem. However, we do not find ourselves in this situation (Fig. 1–4; Fowler and Hobbs 2002, 2003). If we were abnormal for only two measures, which would be the

The common dolphin, *Delphinus delphis*, is a species with body size approximating that of humans. It, along with other species of similar size, can serve as examples of sustainability for our species so as to take body size into account (Photo courtesy of, and copyright by: Larry Hobbs, Inland Whale).

most important to tackle first? There are helpful guidelines that emerge from consideration of complexity, especially the scale of complexity involved in the breadth of biological organization, and it is important to understand them, and that we must gamble, to a certain extent, in making our choices.

One guideline stems from the degree of human departure from the central tendencies of measures of normal ranges of natural variation—the magnitude of abnormality or the extent of problems. If we are at the center of such a distribution (e.g. as we are with regard to trophic level, panel A of Fig. 1), there is not the urgency for change that there is regarding the rates at which we consume biomass (Fig. 1–4). This guideline places more importance on cases where humans are most removed from central locations by treating them as more extreme problems. However, things are never as simple as we would like and this is only a start.

If we restricted our management of human qualities at the individual level in such an approach, we might succeed in achieving a constrained diversity of hair length and not notice that it was more important to pay attention to body temperature and fevers of only a degree or two. We recognize body temperature, body weight, and blood pressure as more important than length of hair or body odor. We recognize this importance, in part, based on the risk of death. However, even at the individual level, we do not always know if we are dealing with things that are sources of short-term or long-term risk, nor what the risks are. One role for paleontologists, epidemiologists, sociologists, and other scientists is to relate the risk of extinction that we may face to the various things that we are doing. However, as seen with all of science, this could result in placing too much importance on extinction. Nevertheless, it would be helpful to know what we are doing to court such risks. It may be helpful to have some sense of things that we are doing as a species that are more like a 41°C fever than are styles of dress and food preferences for individuals.

In this regard the matter of hierarchical complexity becomes useful. Consider another example of the regulation of fisheries. Imagine the hypothetical situation of finding ourselves outside the normal range of natural variation for the age distribution, location, size, and genetic effects of our catches from a particular species. Our understanding of the system (still hypothetical, but now much like what we experience) leads to realizing that solving the problem of age distribution, location, and genetic effects requires reducing the size of the catch (everything is interconnected). This helps focus on the importance of dealing with the size of the catch first, mostly because solving that problem will also contribute a great deal to solving the problem of being outside the normal range of natural variation for other issues as well (e.g. intensity of genetic impact of harvests; systemic management will always involve this kind of consistency, Tenet 1).

The impossibility of short-term solutions to problems before us is nowhere more clear than in the suggestion that people (as individuals) consume less to fit humans within the normal range of natural variation for biomass consumption (Fig. 3). Solving the species-level problem only through changes in individual-level behavior today would put the consumption by individuals outside (far below) the normal range of natural variation for meeting one's minimum daily requirements (it would result in starvation). Other factors and long time frames will have to be dealt with (assuming that nature does not take the upper hand before we have time to find a place within natural limits; Darwin 1953). As is maintained very clearly in much of the scholarly deliberations about such issues, we have to deal with the very sensitive problem of human overpopulation (Fig. 2; American Society of Mammalogists, 1970; Rosenzweig, 1974; Catton, 1980; Ehrlich, 1985; Meffe, 1994; Christensen et al., 1996; Fowler and Hobbs, 2003)—a problem that can be solved only very slowly if we confine ourselves within the normal range of natural variation for mortality and reproductive rates. However, solutions to such problems require that we restrict such rates to levels that are below the mean to make up for ground lost in the centuries during which they have been above the mean.

Summary

Nine core tenets have emerged from reviews of the history and evolution of thought about the management of our use of resources. This consideration was spurred, in part, by recognition of the need to expand the realms of management to include ecosystems as a step toward accounting for complexity. These tenets, and the principles behind them, serve as a basis for rejecting most forms of conventional management while, at the same time, defining the characteristics of an acceptable form of management. Systemic management is one option that meets these criteria by being defined by them; the basic principles are taken into account. Systemic management is management that fully embraces Tenet 3 (Fowler and Hobbs, 2002) and, in so doing, simultaneously succeeds in adhering to all eight of the remaining principles as well as others suggested in the literature. Humans and human institutions are responsible for carrying out management to become sustainable within systems that can, in their own reactions, sustain humans. Until such time that a better form of management materializes, it is imperative that action be taken to solve the problems identified (unless, of course, we choose to ignore the principles and tenets outlined above and let nature take its course and endure the consequences—always an option).

Systemic management avoids using science to construct theories, concepts, or synthetic models to give management advice based on such approaches; it avoids advice of strictly anthropogenic origin. In so doing it circumvents many human limitations, especially those of science. Instead, it is based on empirical measures of what can be observed by science so that nature serves as the model. The things chosen for research, investigation, and measurement are as directly related to the management question as possible. This is a process that does involve theories, concepts, and models, but only in ways to facilitate making observations (e.g. deriving estimates) directly related to management questions. This makes the process of management based on such information as realistic as possible. Nature is the model, and we need to use our best tools to see the inherent guiding information, regardless of the management question.

Acknowledgments

I wish to thank Jason Baker, Jerry Cufley, Jean Fowler, Larry Hobbs, and Alec MacCall, for their many conversations, debates, and discussions that have so significantly contributed to the presentation of management in this paper. I am deeply grateful to Shannon McCluskey for her help in finding and reviewing various pieces of literature referred to in this paper. I thank Gary Duker, Jean Fowler, Willis Hobart, Larry Hobbs, James Lee, Shannon McCluskey, David Rugh, Kim Shelden, Jacki Strader, and several anonymous individuals for very useful reviews and editorial help on previous drafts of this paper. I also want to thank others who have served as coauthors with me on previous papers dealing with systemic management. These are singled out from the host of people who have participated in publishing the many papers and worked as members of so many panels in the efforts that are behind what I have tried to synthesize here. I thank them all in light of the work here being only another step in the building of something that stands on the shoulders of many.

Literature Cited

Agee, J. K., and D. R. Johnson. 1988. A direction for ecosystem management. *In* Agee, J. K., and D. R. Johnson (Editors), Ecosystem management for parks and wilderness, p. 226–232. Univ. Wash. Press, Seattle.

Ahl, V., and T. F. H. Allen. 1996. Hierarchy theory. Columbia Univ. Press, N.Y., 206 p.

Allen, T. F. H., and T. W. Hoekstra. 1992. Toward a unified ecology. Columbia Univ. Press, N.Y., 384 p.

__________ and T. B. Starr. 1982. Hierarchy: perspectives for ecological complexity. Univ. Chicago Press, Chicago, 310 p.

Alpert, P. 1995. Incarnating ecosystem management. Conserv. Biol. 9:952–955.

American Society of Mammalogists. 1970. Resolution on population growth. J. Mammal. 51:856.

Anderson, J. E. 1991. A conceptual framework for evaluating and quantifying naturalness. Conserv. Biol. 5:347–352.

Angermeier, P. L., and J. R. Karr. 1994. Biological integrity versus biological diversity as policy directives—protecting biotic resources. Bioscience 44:690–697.

Aplet, G. H., N. Johnson, J. T. Olson, and V. A. Sample (Editors). 1993. Defining sustainable forestry. Island Press, Wash., D.C., 328 p.

Apollonio, S. 1994. The use of ecosystem characteristics in fisheries management. Rev. Fish. Sci. 2:157–180.

Auerbach, S. I. 1981. Ecosystem response to stress; a review of concepts and approaches.

In G. W. Barrett and R. Rosenberg (Editors), Stress effects on natural ecosystems, p. 29–42. John Wiley and Sons, N.Y.
Bakuzis, E. V. 1969. Forestry viewed in an ecosystem perspective. *In* G. M. Van Dyne (Editor), The ecosystem concept in natural resource management, p. 189–258. Acad. Press, N.Y.
Baron, J., and K. A. Galvin. 1990. Future directions of ecosystem science. Bioscience 40:640–642.
Bartholomew, G. A. 1982. Scientific innovation and creativity: a zoologist's point of view. Am. Zool. 22:227–235.
Bateson, G. 1972. Steps to an ecology of mind. Chandler Publ. Co., San Francisco, 545 p.
__________. 1979. Mind and nature: a necessary unity. Dutton, N.Y., 238 p.
Beissinger, S. R. 1990. On the limits and directions of conservation biology. Bioscience 40:456–457.
Benyus, J. M. 1997. Biomimicry: innovation inspired by nature. William Morrow and Co., Inc., N.Y., 308 p.
Bogan, C. E., and M. J. English. 1994. Benchmarking for best practices. McGraw-Hill, Inc, N.Y., 312 p.
Boulter, M. 2002. Extinction: evolution and the end of man. Columbia Univ. Press, N.Y., 224 p.
Boxwell, R. J., Jr. 1994. Benchmarking for competitive advantage. McGraw-Hill, Inc, N.Y., 224 p.
Brown, J. H. 1994. The ecology of coexistence. Science 363:995–996.
__________. 1995. Macroecology. Univ. Chicago Press, Chicago, 304 p.
__________, G. C. Stevens, and D. M. Kaufman. 1996. The geographic range: size, shape, boundaries, and internal structure. Ann. Rev. Ecol. Syst. 27:597–623.
Cairns, J., Jr. 1986. The myth of the most sensitive species. Bioscience 36:670–672.
__________. 1991. The need for integrated environmental systems management. *In* J. Cairns, Jr. and T. V. Crawford (Editors), Integrated environmental management, p. 5–20. Lewis Publ., Chelsea, Mich.
Calle, E. E., M. J. Thun, J. M. Petrelli, C. Rodriguez, and C. W. Heath. 1999. Body-mass index and mortality in a prospective cohort of U.S. adults. New Engl. J. Med. 341:1097–1105.
Callicott, J. B. 1992. Aldo Leopold's metaphor. *In* R. Costanza, B. G. Norton, and B. D. Haskell (Editors), Ecosystem health: new goals for environmental management, p. 42–56. Island Press, Wash., D.C.
Camp, R. C. 1995. Business process benchmarking: finding and implementing best practices. ASQC Quality Press, Milwaukee, Wis., 464 p.
Canter, L. W. 1996. Environmental impact assessment. McGraw-Hill, Boston, Mass., 660 p.
Capra, F. 1982. The turning point: science society, and the rising culture. Simon and Schuster, N.Y., 464 p.
Carpenter, R. A. 1995. A consensus among ecologists for ecosystem management. Bull. Ecol. Soc. Am. 76:161–162.
Catton, W. R., Jr. 1980. Overshoot: the ecological basis of revolutionary change. Univ. Illinois Press, Chicago, 289 p.
Christensen, N. L., A. M. Bartuska, J. H. Brown, S. R. Carpenter, C. D'Antonio, R. Francis, J. F. Franklin, J. A. MacMahon, R. F. Noss, D. J . Parsons, C. H. Peterson, M. G. Turner, and R. G. Woodmansee. 1996. The report of the Ecological Society of America Committee on the Scientific Basis for Ecosystem Management. Ecol. Appl. 6:665–691.
Clark, T. W., and D. Zaunbrecher. 1987. The Greater Yellowstone Ecosystem: the ecosystem concept in natural resource policy and management. Renew. Res. J. 5:8–16.
__________, E. D. Amato, D. G. Whittemore, and A. H. Harvey. 1991. Policy and programs for ecosystem management in the Greater Yellowstone Ecosystem: an analysis. Conserv. Biol. 5:412–422.
Colborn, T., D. Dumanoski, and J. P. Myers. 1997. Our stolen future: are we threatening our fertility, intelligence, and survival?: a scientific detective story. Penguin Group, N.Y., 316 p.
Conover, D. O., and S. B. Munch. 2002. Sustaining fisheries yields over evolutionary time scales. Science 29:794–796.
Cortner, H. J., and M. A. Moote. 1994. Trends and issues in land and water resources management: setting the agenda for change. Environ. Manage. 18:167–173.
Costanza, R., B. G. Norton, and B. D. Haskell (Editors). 1992. Ecosystem health: new goals for environmental management. Island Press, Wash., D.C., 269 p.
Crawford, R. J. M., P. G. Ryan, and A. J. Williams. 1991. Seabird consumption and production in the Bengueala and western Agulhas ecosystems. S. Afr. J. Mar. Sci. 11:357–375.
Czech, B., and P. R. Krausman. 1997. Implications of an ecosystem management literature review. Wildl. Soc. Bull. 25:667–675.
Darwin, C. G. 1953. The next million years. Doubleday & Co., Garden City, N. Y., 210 p.
Davis, W. S., and T. P. Simon (Editors). 1994. Biological assessment and criteria: tools for water resource planning and decision making. Lewis Publ., Boca Raton, Fla., 415 p.
Dayton, P. K. 1998. Reversal of the burden of proof in fisheries management. Science 279:821–822.
de Rosnay, J. 1979. The macroscope: a new world scientific system. Harper and Row, N.Y., 247 p.
Dunstan, J. C, and K. L. Jope. 1993. Pushing the limits of boundaries. George Wright Forum 10(2):72–78.
Ehrenfeld, D. J. 1993. Beginning again: people and nature in the new millennium. Oxford Univ. Press, N.Y., 194 p.
Ehrlich, P. R. 1985. Ecosystems and ecosystem functions: implications for humankind. *In* R. J. Hoage (Editor), Animal extinctions: what everyone should know, p. 159–173. Smithson. Inst. Press, Wash., D.C.
__________. 1987. Population biology, conservation biology, and the future of humanity. Bioscience 37:757–763.
Eldredge, N. 1991. The miner's canary: unraveling the mysteries of extinction. Prentice Hall Press, N.Y., 246 p.
Emlen, J. M., C. C. Freeman, A. Mills, and J. H. Graham. 1998. How organisms do the right thing: the attractor hypothesis. Chaos 8(3):717–726.
Estes, J. A. 1996. Predators and ecosystem management. Wildl. Soc. Bull. 24:390–396.
Fowler, C. W. 1999. Management of multi-species fisheries: from overfishing to sustainability. ICES J. Mar. Sci. 56:927–932.
__________. 2002. Sustainability. *In* W. F. Perrin, B. Würsig, and H. G. M. Thewissen (Editors), Encyclopedia of marine mammals, p. 1205–1208 . Acad. Press, San Diego, Calif.
__________ and R. Crawford. 2004. Systemic Management of Fisheries in Space and Time: Tradeoffs, Complexity, Ecosystems, Biosphere, Sustainability. Biosphere Conserv. 6:25–42.
__________ and L. Hobbs. 2002. Limits to natural variation: implications for systemic management. Anim. Biodiversity Conserv. 25(2):7–46.
__________ and L. Hobbs. 2003. Is humanity sustainable? Proc. R. Soc. Lond., B. 270:2,579–2,583.
__________ and M. A. Perez. 1999. Constructing species frequency distributions—a step toward systemic management. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-109, 59 p.
__________ and J. A. MacMahon. 1982. Selective extinction and speciation: their influence on the structure and functioning of communities and ecosystems. Am. Nat. 119:480–498.
__________, J. D. Baker, K. E. W. Shelden, P. R. Wade, D. P. DeMaster, and R. C. Hobbs. 1999. Sustainability: empirical examples and management implications. *In* Ecosystem approaches for fishery management, p. 305–314. Univ. Alaska Sea Grant Program, Fairbanks, Rep. AK-SG-99-01.
Francis, G. R. 1993. Ecosystem management. Nat. Res. J. 33:315–345.
Francis, R. C., K. Aydin, R. L. Merrick, and S. Bollens. 1999. Modeling and management of the Bering sea ecosystem. *In* T. R. Loughlin and K. Ohtani (Editors), Dynamics of the Bering Sea, p. 409–433. Univ. Alaska Sea Grant Program, Fairbanks, Rep. AK-SG-99-03.
Franklin, J. F. 1993a. Preserving biodiversity: species, ecosystems, or landscapes? Ecol. Appl. 3:202–205.
________ . 1993b. The fundamentals of ecosystem management with applications in the Pacific Northwest. *In* G. H. Aplet, N. Johnson, J. T. Olson, and V. A. Sample (Editors), Defining sustainable forestry, p. 127–144. Island Press, Wash., D.C.
Fuentes, E. R. 1993. Scientific research and sustainable development. Ecol. Appl. 3:576–577.
Gaston, K. J., and T. M. Blackburn. 2000. Patterns and process in macroecology. Blackwell Sci., Oxford., 377 p.
Gillon, S. M . 2000. That's not what we meant to do. Norton & Co., N.Y., 288 p.
Gleick, J. 1987. Chaos: making a new science. Penguin Books, N.Y., 354 p.
Gödel, K. 1931. Uber formal unentscheidbar satze der principia mathematica und verwander systeme I. Monatsh. Math. Phys. 38:173–198.
Goudie, A. 1993. The human inpact on the natural environment. MIT Press, Camb., Mass., 432 p.
Grime, J. P. 1989. The stress debate: symptoms of impending synthesis? Biol. J. Linn. Soc. 37:3–17.
Grizzle, R. E. 1994. Environmentalism should include human ecological needs. Bioscience 44:263–268.
Grumbine, R. E. 1994. What is ecosystem management? Conserv. Biol. 8:27–38.
________. 1997. Reflections on "What is ecosystem management?" Conserv. Biol. 11:41–47.
Haeuber, R., and J. Franklin. 1996. Forum: perspectives on ecosystem management. Ecol. Appl. 6:692–693.
Hall, S. 1999. Effects of fishing on marine eco-

systems and communities. Fishing News Books. Oxford., 296 p.
Hassan, F. A. 1981. Demographic archeology. Acad. Press, N.Y., 298 p.
Hern, W. M. 1993. Is human culture carcinogenic for uncontrolled population growth and ecological destruction? Bioscience 43:768–773.
Holling, C. S. 1993. Investing in research for sustainability. Ecol. Appl. 3:552–555.
________ and G. K. Meffe. 1996. Command and control and the pathology of natural resource management. Conserv. Biol. 10:328–337.
Holt, S. J., and L. M. Talbot. 1978. New principles for the conservation of wild living resources. Wildl. Monogr. 59:5–33.
Huntley, B. J., E. Ezcurra, E. R. Fuentes, K. Fujii, P. J. Grubb, W. Haber, J. R. E. Harger, M. M. Holland, S. A. Levin, J. Lubchenco, H. A. Mooney, V. Neronov, I. Noble, H. R. Pulliam, P. S. Ramakrishnan, P. G. Risser, O. Sala, J. Sarukhan, and W. G. Sombroek. 1991. A sustainable biosphere: the global perspective. Ecol. Internat. 20:1–14.
Hyams, E. 1976. Soil and civilization. Harper and Row, N.Y., 312 p.
Ingram, G., and R. Molnar. 1990. The structure of life. Aust. Nat. Hist. 23:416–417.
Interagency Ecosystem Management Task Force. 1995. The ecosystem approach: healthy ecosystems and sustainable economics. Vol. I, Overview. Interagency Ecosystem Manage. Task Force, U.S. Dep. Inter., Wash., D.C., 55 p.
Jackson, J. B. C., M. X. Kirby, W. H. Berger, K. A. Bjorndal, L. W. Botsford, B. J. Bouroque, R. H. Bradbury, R. Cooke, J. Erlandson, J. A. Estes, T. P. Hughes, S. Kidwell, C. B. Lange, H. S. Lenihan, J. M. Pandolfi, C. H. Peterson, R. S. Steneck, M. J. Tegner and R. R. Warner. 2001. Historical overfishing and the recent collapse of coastal ecosystems. Science 293:629–638.
Jarvis, S. 1978. Extinction by default? A philosophical argument of education to enable survival. Univ. Wash., Seattle, Wash., MS Thesis, 119 p.
Jenkins, R. E. 1985. The identification, acquisition, and preservation of land as a species conservation strategy. *In* R. J. Hoage (Editor), Animal extinctions: what everyone should know, p. 129–145. Smithson. Instit. Press, Wash., D.C.
Johnson, D. R., and J. K. Agee. 1988. Introduction to ecosystem management. *In* J. K. Agee and D. R. Johnson (Editors), Ecosystem management for parks and wilderness, p. 3–14. Univ. Wash. Press, Seattle, Wash.
Johnston, C. M. 1992. The wisdom of limits. In Context 32:48–51.
Jordan, W. R., III, M. E. Gilpin, and J. D. Aber (Editors). 1987. Restoration ecology: a synthetic approach to ecological research. Cambridge Univ. Press, N.Y., 352 p.
Jørgensen, S. E., and F. Müller (Editors). 2000. Handbook of ecosystem theories and management. Lewis Publ., Boca Raton, Fla., 584 p.
________ , B. C. Patten, and M. Straskraba. 1999. Ecosystems emerging: 3. Openness. Ecol. Modelling 117(1):41–64.
Kaiser, M. J., and S. J. de Groot. 1999. Effects of fishing on non-target species and habitats. Fishing News Books. Oxford., 416 p.
Kauffman, S. A. 1993. The origins of order: self-organization and selection in evolution. Oxford Univ. Press, N.Y., 734 p.
King, A. W. 1993. Considerations of scale and hierarchy. *In* S. Woodley, G. Francis, and J. Kay (Editors), Ecological integrity and the management of ecosystems, p. 19–45. St. Luicie Press, Delray Beach, Fla.
Knight, R. L., and S. F. Bates (Editors). 1995. A new century for natural resource management. Island Press, Wash., D.C., 398 p.
Koehl, M. A. R. 1989. Discussion: from individuals to populations. *In* J. Roughgarden, R. M. May, and S .A. Levin (Editors), Perspectives in ecological theory, p. 39–53. Princeton Univ. Press, Princeton, N.J.
Koestler, A. 1987. Janus: a summing up. Random House, N.Y., 354 p.
Lackey, R. T. 1995–96. Ecosystem management: implications for fisheries management. Renew. Res. J. 13:11–13.
Laughlin Jr., C. D., and I. A. Brady (Editors). 1978. Extinction and survival in human populations. Columbia Press, Irvington on Hudson, N.Y., 352 p.
Lederberg, J. 1973. The genetics of human nature. Soc. Res. 40:375–378.
Lee, K. N. 1993a. Greed, scale mismatch, and learning. Ecol. Appl. 3:560–564.
________ . 1993b. Compass and gyroscope: integrating science and politics for the environment. Island Press, Covelo, Calif., 243 p.
Lewin, R. 1992. Complexity: life at the edge of chaos. Macmillan, N.Y., 208 p.
Lewis, J. K. 1969. Range management viewed in the ecosystem framework. *In* G. M. Van Dyne (Editor), The ecosystem concept in natural resource management, p. 97–187. Acad. Press, N.Y.
Likens, G. E. 1992. Ecosystem approach: its use and abuse. Ecol. Instit., Olendorf/Luhe, Germany, 166 p.
Livingston, P. A. 1993. Importance of predation by groundfish, marine mammals and birds on walleye pollock *Theragra chalcogramma* and Pacific herring *Clupea pallasi* in the eastern Bering Sea. Mar. Ecol. Progr. Ser. 102:205–215.
Loucks, O. L. 1985. Looking for surprise in managing stressed ecosystems. Bioscience 35:428–432.
Lovejoy, T. E., J. M. Rankin, R. O. Bierregaard, Jr., K. S. Brown, Jr., L. A. Emmons, and M. E. VanderVoort. 1984. Ecosystem decay of Amazon forest remnants. *In* M. H. Nitecki (Editor), Extinctions, p. 295–326. Univ. Chicago Press, Chicago.
Lubchenco, J., A. M. Olson, L. A. Brubaker, S. R. Carpenter, M. M. Holland, S. P. Hubbell, S. A. Levin, J. A. MacMahon, P. A. Matson, J. M. Melillo, H. A. Mooney, C. H. Peterson, H. R. Pulliam, L. A. Real, P. J. Regal, and P. G. Risser. 1991. The sustainable biosphere initiative: an ecological research agenda. Ecology 72:371–412.
Ludwig, D., R. Hilborn, and C. Walters. 1993. Uncertainty, resource exploitation, and conservation: lessons from history. Science 260:17–36.
Lueck, D. 2000. Unintended consequences. Forum for applied research and public policy. 15(3)16–22.
Maerz, J. C. 1994. Ecosystem management: a summary of the ecosystem management roundtable of 19 July 1993. Bull. Ecol. Soc. Am. 75:93–95.
Magnuson, J. J. 1986. The fishing problem. Science 232:1,447.
Major, J. 1969. Historical development of the ecosystem concept. *In* G. M. Van Dyne (Editor), The ecosystem concept in natural resource management, p. 9–22. Acad. Press, N.Y.
Makous, W. 2000. Limits to our knowledge. Science 287:1,399.
Malone, C. R. 1995. Ecosystem management: status of the Federal initiative. Bull. Ecol. Soc. Am. 76:158–161.
Mangel, M., L. M. Talbot, G. K. Meffe, M. T. Agardy, D. L. Alverson, J. Barlow, D. B. Botkin, G. Budowski, T. Clark, J. Cooke, R. H. Crozier, P. K. Dayton, D. L. Elder, C. W. Fowler, S. Funtowicz, J. Giske, R. J. Hofman, S. J. Holt, S. R. Kellert, L. A. Kimball, D. Ludwig, K. Magnusson, B. S. Malayang, C. Mann, E. A. Norse, S. P. Northridge, W. F. Perrin, C. Perrings, R. M. Peterman, G. B. Rabb, H. A. Regier, J. E. Reynolds III, K. Sherman, M. P. Sissenwine, T. D. Smith, A. Starfield, R. J. Taylor, M. F. Tillman, C. Toft, J. R. Twiss, Jr., J. Wilen, and T. P. Young. 1996. Principles for the conservation of wild living resources. Ecol. Appl. 6:338–362.
May, R. M. 1989. Levels of organization in ecology. *In* J. M. Cherrett (Editor), Ecological concepts: the contribution of ecology to an understanding of the natural world, p. 339–363. Blackwell Sci., Boston, Mass.
Mazur, L. A. 1994. Beyond the numbers: an introduction and overview. *In* L. A. Mazur (Editor), Beyond the numbers, p. 1–20. Island Press, Wash., D.C.
McCormick, F. J. 1999. Principles of ecosystem management and sustainable development. *In* J. D. Peine (Editor), Ecosystem management for sustainability: principles and practices illustrated by a regional biosphere reserve cooperative, p. 3–21. Lewis Publ., Boca Raton, Fla.
McDonnell, M. J., and S. T. A. Pickett (Editors). 1993. Humans as components of ecosystems: the ecology of subtle human effects and populated areas. Springer-Verlag, N.Y., 386 p.
McIntyre, M. E. 1998. Lucidity and science III: hyperdredulity, quantum mechanics, and scientific truth. Interdisciplinary Sci. Rev. 23:29–70.
McNeill, W. H. 1993. Patterns of disease emergence in history. *In* S. S. Morse (Editor), Emerging viruses, p. 29–36. Oxford Univ. Press, N.Y.
Meadows, D. H., D. L. Meadows, and J. Randers. 1992. Beyond the limits. Chelsea Green, Post Mills, Vt., 300 p.
Meffe, G. K. 1994. Human population control: the missing awareness. Conserv. Biol. 8:310–313.
Merton, R. K. 1936. The unanticipated consequences of purposive social action. Am. Sociol. Rev. 1(6):894–904.
Meyer, W. B., and B. L. Turner (Editors). 1994. Changes in land use and land cover: a global perspective. Camb. Univ. Press, N.Y., 537 p.
Mines, S. 1971. The last days of mankind; ecological survival or extinction. Simon and Schuster, N.Y., 319 p.
Mladenhoff, D. J., and J. Pastor. 1993. Sustainable forest ecosystems in the northern hardwood and conifer forest region: concepts and management. *In* G. H. Aplet, N. Johnson, J. T. Olson, and V. A. Sample (Editors), Defining sustainable forestry, p. 145–180. Island Press, Wash., D.C.
Mooney, H. A., and O. E. Sala. 1993. Science and sustainable use. Ecol. Appl. 3:564–566.
Munn, R. E. 1993. Monitoring for ecosystem integrity. *In* S. Woodley, G. Francis, and J.

Kay (Editors), Ecological integrity and the management of ecosystems, p. 105–115. St. Luicie Press, Delray Beach, Fla.
Munro, D. A., and M. W. Holdgate (Editors). 1991. Caring for the Earth: a strategy for sustainable living. IUCN, Gland, Switzerland, 200 p.
Murawski, S. A. 1991. Can we manage our multispecies fisheries? Fisheries 16:5–13.
Myers, N. 1989. Extinction rates past and present. Bioscience 39:39–41.
________ . 1993. The question of linkages in environment and development. Bioscience 43:302–310.
Myers, R., and B. Worm. 2003. Rapid worldwide depletion of predatory fish communities. Nature 423:280–283.
Naiman, R. J. (Editor). 1992. Watershed management: balancing sustainability and environmental change. Springer-Verlag, N.Y., 542 p.
________ , J. J. Magnuson, D. M. McKnight, J. A. Stanford, and J. R. Karr. 1995. Freshwater ecosystems and their management: a national initiative. Science 270:584–584.
Nash, J. 1950. Non-cooperative games. Princeton University Mathematics Department, Ph.D. thesis. Princeton, N.J., 27 p.
Nash, S. 1991. What price nature? Bioscience 41:677–680.
National Commission of the Environment Staff. 1993. Choosing a sustainable future: the Report of the National Commission of the Environment. Island Press, Wash., D.C. 190 p.
NMFS. 1999. Ecosystem-based fishery management: a report to congress. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv. Ecosystem Principles Advis. Panel, Wash., D.C., 54 p.
NRC. 1996. Upstream: salmon and society in the Pacific Northwest. Natl. Res. Counc., Natl. Acad. Press, Wash., D.C., 452 p.
________ . 1999. Sustaining marine fisheries. Natl. Res. Counc., Natl. Acad. Press, Wash., D.C., 164 p.
Nixon, S. W., and J. N. Kremer. 1977. Narragansett Bay—the development of a composite simulation model for a New England estuary. *In* C. A. S. Hall and J. W. Day (Editors), Ecosystem modeling in theory and practicean introduction with case histories, p. 622–673. John Wiley, N.Y.
Norton, B. G. 1987. Why preserve natural variety? Princeton Univ. Press, Princeton, N.J., 281 p.
________ . 1991. Ecosystem health and sustainable resource management. *In* R. Costanza (Editor), Ecological economics: the science and management of sustainability, p. 23–41. Columbia Univ. Press, N.Y.
________ . 1994. Ecology and prophecy for the new millennium. Bioscience 44:37–39.
Noss, R. F. 1990a. Can we maintain biological and ecological integrity? Conserv. Biol. 4:241–243.
________ . 1990b. Indicators for monitoring biodiversity: a hierarchical approach. Conserv. Biol. 4:355–364.
________ . 1993. Sustainable forestry or sustainable forests? *In* G. H. Aplet, N. Johnson, J. T. Olson, and V. A. Sample (Editors), Defining sustainable forestry, p. 17–43. Island Press, Wash., D.C.
________ and A. Y. Cooperrider. 1994. Saving nature's legacy: protecting and restoring biodiversity. Island Press, Wash., D.C., 417 p.
O'Neill, M. B. 1999. Executive coaching with backbone and heart. Jossey-Bass, San Francisco, Calif., 272 p.
O'Neill, R. V. 1989. Perspectives in hierarchy and scale. *In* J. Roughgarden, R. M. May and S. A. Levin (Editors), Perspectives in ecological theory, p. 140–156. Princeton Univ. Press, Princeton, N.J.
________ , D. L. DeAngelis, J. B. Waide, and T. F. H. Allen. 1986. A hierarchical concept of ecosystems. Princeton Univ. Press, Princeton, N.J., 261 p.
Orians, G. H. 1990. Ecological concepts of sustainability. Environment 32:10–15, 34–39.
________ , G. M. Brown, Jr., W. E. Kunin, and J. E. Swierzbinski (Editors). 1990. The preservation and valuation of biological resources. Univ. Wash. Press, Seattle, 301 p.
Ostermeier, D. M. 1998. The role of institutions in ecosystem management. *In* J. D. Peine (Editor), Ecosystem management for sustainability: principles and practices illustrated by a regional biosphere reserve cooperative, p. 457–474., Lewis Publ., Boca Raton, Fla.
Overholtz, W. J., S. A. Murawski, and K. L. Foster. 1991. Impact of predatory fish, marine mammals, and seabirds on the pelagic fish ecosystem of the northeastern USA. ICES Mar. Sci. Symp. 193:198–208.
Ovington, J. D. 1975. Strategies for the management of natural and man-made ecosystems. *In* W. H. van Dobben and R. H Lowe-McConnell (Editors), Unifying concepts in ecology, p. 239–246. Dr. W. Junk b. v., The Hague, the Netherlands and Cent. Agric. Publ. Documentation, Wageningen, the Netherlands.
Page, T. 1992. Environmental existentialism. *In* R. Costanza, B. G. Norton, and B. D. Haskell (Editors), Ecosystem health: new goals for environmental management, p. 97–123. Island Press, Wash., D.C.
Pastor, J. 1995. Ecosystem management, ecological risk, and public policy. Bioscience 45:286–288.
Patten, D. T. 1991. Human impacts in the greater Yellowstone: evaluating sustainability goals and eco-redevelopment. Conserv. Biol. 5:405–411.
Pauly, D., V. Christensen, J. Dalsgaard, R. Froese, and F. Torres, Jr. 1998. Fishing down marine food webs. Science 279:860–863.
Pennycuick, C. J. 1992. Newton rules biology: a physical approach to biological problems. Oxford Univ. Press, N.Y., 111 p.
Peterman, R. M., and M. M'Gonigle. 1992. Statistical power analysis and the precautionary principle. Mar. Pollut. Bull. 24:231–234.
Peters, R. H. 1991. A critique for ecology. Camb. Univ. Press, N.Y., 400 p.
Pew Oceans Commission. 2003. America's living oceans; charting a course for sea change: A report to the nation: recommendations for a new ocean policy. Pew Oceans Commission, 2101 Wilson Blvd., Suite 550, Arlington, VA 22201, 144 p.
Pfister, R. D. 1993. The need and potential for ecosystem management in forests of the inland west. *In* G. H., Aplet, N. Johnson, J. T. Olson, and V. A. Sample (Editors), Defining sustainable forestry, p. 217–239. Island Press, Wash., D.C.
Pickett, S. T. A., and R. S. Ostfeld. 1995. The shifting paradigm in ecology. *In* R. L. Knight and S. F. Bates (Editors), A new century for natural resource management, p. 261–278. Island Press, Wash., D.C.
________ , V. T. Parker, and P. L. Fiedler. 1992. The new paradigm in ecology: implications for conservation biology above the species level. *In* P. L. Jain and S. K. Jain (Editors), Conservation biology: the theory and practice of nature conservation, preservation, and management, p. 65–88. Chapman and Hall, N.Y.
Pimentel, D. 1966. Complexity of ecological systems and problems in their study and management. *In* K. E. F. Watt (Editor), Systems analysis and ecology, p. 15–35. Acad. Press, N.Y.
Pimm, S. L. 1982. Food webs. Chapman and Hall, Lond., 219 p.
________ . 1991. The balance of nature? Ecological issues in the conservation of species in communities. Univ. Chicago Press, Chicago, 434 p.
Policansky, D., and J. J. Magnuson. 1998. Genetics, metapopulations, and ecosystem management of fisheries. Ecol. Appl. 8(suppl.): S119–S123.
Ponting, C. 1991. A green history of the world: the environment and the collapse of great civilizations. Sinclair-Stevenson, Lond., 432 p.
Prigogine, I., and I. Stengers. 1984. Order out of chaos: man's new dialogue with nature. Bantam Books, N.Y., 349 p.
Rapport, D. J. 1989. What constitutes ecosystem health? Perspectives Biol. Medicine 33:120–132.
________ . 1992. What is clinical ecology? *In* R. Costanza, B. G. Norton, and B. D. Haskell (Editors), Ecosystem health: new goals for environmental management, p. 144–156. Island Press, Wash., D.C.
________ , H. A. Regier, and C. Thorpe. 1981. Diagnosis, prognosis, and treatment of ecosystems under stress. *In* G. W. Barrett and R. Rosenberg (Editors), Stress effects on natural ecosystems, p. 269–280. John Wiley and Sons, N.Y.
________ , H. A. Regier, and T. C. Hutchinson. 1985. Ecosystem behavior under stress. Am. Nat. 125:617–640.
Rasmussen, L. L. 1996. Earth community Earth ethics. Orbis Books, Maryknoll, N.Y., 367 p.
Ray, G. C., and J. F. Grassle. 1991. Marine biological diversity: a scientific program to help conserve marine biological diversity is urgently required. Bioscience 41:453–457.
Reed, C. G. 1989. More on extinction. Bioscience 39:357–358.
Redman, C. L. 1999. Human inpact on ancient environments. Univ. Ariz. Press, Tucson, 255 p.
Regal, P. J . 1996. Metaphysics in genetic engineering: cryptic philosophy and ideology in the "science" of risk assessment. *In* A. Van Dommelen (Editor), Coping with deliberate release: the limits of risk assessment, p. 15–32. Int. Cent. Human Public Affairs, Tilburg, the Netherlands.
Restrepo, V. R., G. G. Thompson, P. M. Mace, W. L. Gabriel, L. L. Low, A. D. MacCall, R. D. Methot, J. E. Powers, B. L. Taylor, P. R. Wade, and J. F. Witzig. 1998. Technical guidance on the use of precautionary approaches to implementing national standard 1 of the Magnuson-Stevens Fishery Conservation and Management Act. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-F/SPO-31, 54 p.
Rohman, C. 1999. A world of ideas. Ballantine Books, N.Y., 477 p.
Rosenberg, A. 1985. The structure of biological science. Camb. Univ. Press, N.Y., 281 p.

Rosenzweig, M. L. 1974. And replenish the Earth: the evolution, consequences, and prevention of overpopulation. Harper and Row, N.Y., 304 p.

Roughgarden, J. 1989. The structure and assembly of communities. *In* J. Roughgarden, R. M. May, and S. A. Levin (Editors), Perspectives in ecological theory, p. 203–226. Princeton Univ. Press, Princeton, N.J.

Safina, C. 1995. The world's imperiled fish. Sci. Am. 273(5):46–53.

Salthe, S. N. 1985. Evolving hierarchical systems: their structure and representation. Columbia Univ. Press, N.Y., 343 p.

Salwasser, H. 1988. Managing ecosystems for viable populations of vertebrates: a focus on biodiversity. *In* J. K. Agee and D. R. Johnson (Editors), Ecosystem management for parks and wilderness, p. 87–104. Univ. Wash. Press, Seattle.

________ . 1993. Sustainability needs more than better science. Ecol. Appl. 3:587–589.

________ , H., D. W. MacCleery, and T. A. Snellgrove. 1993. An ecosystem perspective on sustainable forestry and new directions for the U.S. national forest system. *In* G. H. Aplet, N. Johnson, J. T. Olson, and V. A. Sample (Editors), Defining sustainable forestry, p. 44–89. Island Press, Wash., D.C.

Salzman, L. 1994. Economics is ecology. Bioscience 44:514.

Sampson, F. B., and F. L. Knopf. 1996. Ecosystem management: selected readings. Springer-Verlag, N.Y., 462 p.

Santos, M. A. 1990. Managing planet Earth: perspectives on population, ecology, and the law. Bergin and Garvey, N.Y., 172 p.

Schaeffer, D. J., and D. K. Cox. 1992. Establishing ecosystem threshold criteria. *In* R. Costanza, B. G. Norton, and B. D. Haskell (Editors), Ecosystem health: new goals for environmental management, p. 157–169. Island Press, Wash., D.C.

________ , E. E. Herricks, and H. W. Kerster. 1988. Ecosystem health: 1. Measuring ecosystem health. Environ. Manage. 12:445–455.

Schnute, J. T., and L. J. Richards. 2001. Use and abuse of fishery models. Can. J. Fish. Aquat. Sci. 58:10–17.

Schoener, T. W. 1986. Overview: kinds of ecological communities—ecology becomes pluralistic. *In* J. Diamond and T. J. Case (Editors), Community ecology, p. 467–479. Harper and Row, N.Y.

Schramm, H. L., Jr., and W. A. Hubert. 1996. Ecosystem management: implications for fisheries management. Fisheries 21:6–11.

Sherman, K., L. M. Alexander, and B. D. Gold. 1991. Food chains, yields, models, and management of large marine ecosystems. Westview Press, Boulder, Colo., 320 p.

Sieving, K, and Bio Sci 296A. 1994. The population crisis demands a focused agenda. Conserv. Biol. 8:303–307.

Silver, C. S., and R. S. DeFries (Editors). 1990. One Earth, one future: our changing global environment. Nat. Acad. Press, Wash., D.C., 196 p.

Simberloff, D. 1988. The contribution of population and community biology to conservation science. Ann. Rev. Ecol. Syst. 19:473–511.

Sissenwine, M. P., and N. Daan. 1991. An overview of multispecies models relevant to the management of living marine resources. Int. Counc. Explor. Sea Mar. Sci. Symp. 193:6–11.

Slobodkin, L. B. 1986. The role of minimalism in art and science. Am. Nat. 127:257–265.

Slocombe, D. S. 1993. Implementing ecosystem-based management. Bioscience 43:612–622.

Smith, F. E. 1977. Comments revisited—or, what I wish I had said. *In* G. S. Innis (Editor), New directions in the analysis of ecological systems, Part 2, p. 231–235. Soc. Computer Simulation, La Jolla, Calif.

Smith, T. D. 1994. Scaling in fisheries: the science of measuring the effects of fishing, 1855–1955. Camb. Univ. Press, N.Y., 392 p.

Soulé, M. E. 1985. What is conservation biology? Bioscience 35:727–734.

Spendolini, M. J. 1992. The benchmarking book. Am. Manage. Association, N.Y., 209 p.

Stanley, T. R., Jr. 1995. Ecosystem management and the arrogance of humanism. Conserv. Biol. 9:255–262.

Steedman, R., and W. Haider. 1993. Applying notions of ecological integrity. *In* S. Woodley, G. Francis, and J. Kay (Editors), Ecological integrity and the management of ecosystems, p. 47–60. St. Luicie Press, Delray Beach, Fla.

Sutherland, W. J. 1990. Evolution and fisheries. Nature 344:814–815.

Swimme, B., and T. Berry. 1994. The universe story. Harper, San Francisco, Calif., 320 p.

Tenner, E. 1996. Why things bite back: technology and the revenge of unintended consequences. Knopf, N.Y., 349 p.

Terborgh, J. 1974. Preservation of natural diversity: the problem of extinction prone species. Bioscience 24:715–722.

Thompson, J. N. 1994. The coevolutionary process. Univ. Chicago Press, Chicago, Ill., 352 p.

Thorpe, W. H. 1974. Reductionism in biology. *In* F. J. Ayala and T. Dobzhansky (Editors), Studies in the philosophy of biology: reduction and related problems, p. 109–138. Macmillan, Lond.

Toman, M. A. 1993. Defining an economics of sustainable forestry: general comments. *In* G. H. Aplet, N. Johnson, J. T. Olson, and V. A. Sample (Editors), Defining sustainable forestry, p. 270–279. Island Press, Wash., D.C.

Tudge, C. 1989. The rise and fall of *Homo sapiens sapiens*. *In* W. G. Chaloner and A. Hallam (Editors), Evolution and extinction: proceedings of a joint symposium of the Royal Society of the Linnean Society held on 9 and 10 November 1989, p. 239–248. R. Soc., Lond.

Turner, B. L., W. C. Clark, R. W. Kates, J. F. Richards, J. T. Mathews, and W. B. Meyer (Editors). 1990. The Earth as transformed by human action; global and regional changes in the biosphere over the past 300 years. Cambridge Univ. Press, N.Y., 736 p.

Uhl, C., A. Anderson, and G. Fitzgerald. 2000. Higher education: good for the planet? Bull. Ecol. Soc. Am. 81:152–156.

Ulanowicz, R. E. 1992. Ecosystem health and trophic flow networks. *In* R. Costanza, B. G. Norton, and B. D. Haskell (Editors), Ecosystem health: new goals for environmental management, p. 190–206. Island Press, Wash., D.C.

Vallentyne, J. R. 1993. Biospheric foundations of the ecosystem approach to environmental management. J. Aquat. Ecosyst. Health 2:9–13.

________ and A. L. Hamilton. 1988. Managing the human uses and abuses of aquatic resources in the Canadian ecosystem. Can. Bull. Fish. Aquat. Sci. 215:513–533.

van Dobben, W. H., and R. H. Lowe-McConnell. 1975. Preface. *In* W. H. van Dobben and R. H. Lowe-McConnell (Editors), Unifying concepts in ecology, p. 5–8. Dr. W. Junk b. v., The Hague, the Netherlands, and Cent. Agric. Publ. Documentation, Wageningen, the Netherlands.

Van Dyne, G. M. 1969. Implementing the ecosystem concept in training in the natural resource science. *In* G. M. Van Dyne (Editor), The ecosystem concept in natural resource management, p. 328–368. Acad. Press, N.Y.

Vitousek, P. M., H. A. Mooney, J. Lubchenco, and J. M. Melillo. 1997. Human domination of Earth's ecosystems. Science 277:494–499.

Vrijenhoek, R. C. 1989. Population genetics and conservation. *In* D. Western and M. Pearl (Editors), Conservation for the twenty-first century, p. 89–98. Oxford Univ. Press, N.Y.

Wagner, F. H. 1977. Species vs. ecosystem management. Trans. 42nd N. Am. Wildl. Natural Resour. Conf. 42:14–42.

Wallace, R. L. 1994. The Marine Mammal Commission compendium of selected treaties, international agreements, and other relevant documents on marine resources, wildlife, and the environment. U.S. Mar. Mammal Comm., Wash., D.C., vol. 1–3, 3,547 p.

Walters, C. 1986. Adaptive management of renewable resources. Macmillan, N.Y., 374 p.

________ . 1992. Perspectives on adaptive policy design in fisheries management. *In* S. K. Jain and L. W. Botsford (Editors), Applied population biology, p. 249–262. Kluwer Academic, Dordrecht, Netherlands.

Westman, W. E. 1990. Managing for biodiversity: unresolved science and policy questions. Bioscience 40:26–33.

Wilcox, B. A., and D. D. Murphy. 1985. Conservation strategy: the effects of fragmentation on extinction. Am. Nat. 125:879–887.

Wilber, K. 1995. Sex, ecology, spirituality: the spirit of evolution. Shambhala Publ., Boston, 831 p.

Williams, G. C. 1992. Natural selection: domains, levels, and challenges. Oxford Univ. Press, N.Y., 288 p.

Wood, C. A. 1994. Ecosystem management: achieving the new land ethic. Renew. Res. J. 12:6–12.

Woodley, S. 1993. Monitoring and measuring ecosystem integrity in Canadian national parks. *In* S. Woodley, G. Francis, and J. Kay (Editors), Ecological integrity and the management of ecosystems, p. 155–176. St. Luicie Press, Delray Beach, Fla.

________ , J. J. Kay, and G. R. Francis (Editors). 1993. Ecological integrity and the management of ecosystems. St. Luicie Press, Delray Beach, Fla., 220 p.

Woodruff, D. S. 1989. The problems of conserving genes and species. *In* D. Western and M. Pearl (Editors), Conservation for the twenty-first century, p. 76–88. Oxford Univ. Press, N.Y.

Woodwell, G. M. (Editor). 1990. The earth in transition; patterns and processes of biotic impoverishment. Camb. Univ. Press, N.Y., 544 p.

World Conservation Monitoring Centre (WCMC). 1992. Global biodiversity. Chapman and Hall, N.Y., 585 p.

Appendix 1

Management Tenets and Principles Since the 1970's

Czech and Krausman's (1997) literature review on "ecosystem management" elaborates on important principles and guidelines for management at the ecosystem level, especially as produced by individuals or small groups of coauthors. This is in contrast to the products of panels and committees exemplified by Christensen et al., 1996. Later publications by individuals or informal groups also contain lists of various tenets (e.g. Fowler et al., 1999; Francis et al., 1999; and Uhl et al., 2000). This appendix presents a summary of principles and tenets of management as represented in the literature since 1970, largely supplementing the review by McCormick (1999).

First Airlie House:

Principles that were developed in the first Airlie House meeting were reported in Holt and Talbot (1978) as:

1) The ecosystem should be maintained in a desirable state such that:
   a) consumptive and nonconsumptive values could be maximized on a continuing basis,
   b) present and future options are ensured, and
   c) risk of irreversible changes 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.

Ecosystem Management Workshop:

A workshop was held at the University of Washington's Pack Forest in 1987 to address the concept of ecosystem management (Agee and Johnson, 1988). The principles put forward by the workshop were:

1) Cooperation and open negotiation are important to success. Given that park and wilderness ecosystems are bounded politically, and that things important to people move across those boundaries, cooperation, honesty, and openness are essential.
2) Different agencies and neighbors have different mandates, objectives, and constituencies to which the interested parties must be sensitive.
3) Success should be measured by results—progress toward goals of component condition and ecosystem maintenance—not by amount or quality of coordination.
4) Threshold management goals are established by the park and wilderness legislation. Setting further goals will be site-specific process taking account of the context of the park or wilderness within its regional and national social matrix.
5) Clearly defined problems have greater chance of being resolved.
6) Over the long term, ecosystem management must accommodate multiple uses at a regional scale and dominant or restricted use at the unit or site scale.
7) High quality information is necessary to identify trends and respond to them intelligently and deliberately.
8) Social, political, and environmental issues must be viewed in a system context, not as individual issues. Individual components may be the focus within that context.
9) All management is a long-term experiment, and decisions are always made with less than complete information.

Costanza et al. (1992):

In 1992, Costanza et al. (1992) refer to Norton (1991) in listing five axioms suggested for management:

1) The axiom of dynamism: nature is more profoundly a set of processes than a collection of objects; all is in flux.
2) The axiom of relatedness: all processes are related to all other processes.
3) The axiom of hierarchy: processes are not related equally but unfold in systems within systems, which differ mainly regarding the temporal and spatial scale on which they are organized.
4) The axiom of creativity: the autonomous processes of nature are creative and represent the basis for all biologically based productivity. The vehicle of that creativity is energy flowing through systems which in turn find stable contexts in larger systems, which provide sufficient stability to allow self-organization within them through repetition and duplication.
5) The axiom of differential fragility: the ecological systems, which form the context of all human activities, vary on the extent to which they can absorb and equilibrate human-caused disruptions in their autonomous processes.

Second Airlie House:

In 1994, the principles and tenets of management listed at the first Airlie House meeting were reconsidered and one principle (the first point listed below) and six tenets (points 2–7) were developed at the second Airlie House meeting (paraphrased from Mangel et al., 1996):

1) Sustainability is inconsistent with unlimited growth of human consumption of, and demand for, resources.
2) Present and future options are to be achieved by maintaining biological diversity at genetic, species, population, and ecosystem levels. Neither the resource nor other components of the ecosystem should be perturbed beyond natural boundaries of variation.
3) Assessment (including ecological and sociological effects) of resource use should precede both proposed use and proposed restriction or expansion of ongoing use of a resource.

4) Management must be based on understanding of the structure and dynamics of ecosystems while accounting for both ecological and sociological factors.
5) The full range of knowledge and skills from the natural and social sciences must be brought to bear in dealing with conservation problems.
6) 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.
7) Effective conservation requires communication that is interactive, reciprocal, and continuous.

Moote et al.:

At about the same time Moote et al. (text footnote 2) compiled a list of points that are a mixture of definitions, tenets, and principles that they found important as based on a review of literature dealing with management, again primarily "ecosystem management":

Ecosystem management is a management philosophy which focuses on desired states, rather than system outputs, and which recognizes the need to protect or restore critical ecological components, functions, and structures in order to sustain resources in perpetuity.

1) Socially Defined Goals and Management Objectives
Desired future conditions and the means by which we choose to achieve these conditions are social values. Therefore ecosystem management, like all forms of management, is a socially defined process. There is nevertheless a recognized need for human society to adapt its activities to protect crucial ecological processes.

2) Integrated, Holistic Science
Ecosystem management uses a holistic approach, rather than focusing on specific system outputs. It attempts to conserve biodiversity from the genetic to the community level. Ecosystems are recognized as open, changing, complex systems. Ecosystem management focuses on the dynamic interrelations of systems components—including social, political, economic, biological, and physical features—and requires better understanding of each of these components and their interrelations. Humans are recognized as a part of ecosystems.

3) Broad Spatial and Temporal Scales
Specific scales of management will be determined individually for each system, based on societal values and goals. In general, however, ecosystem management requires management on larger spatial and longer temporal time scales than has been the norm in resource management. Ecosystem management means management across ecological, political, generational, and ownership boundaries.

4) Collaborative Decision Building
Successful planning for ecosystem management must be sensitive to the different mandates, objectives, and constituencies of agencies and landowners. Therefore, there is a need for cooperative, integrated data collection and planning characterized by open communication among scientists, resource management agencies, and private interests. Participants should strive for joint organizational and community learning that acknowledges the values and expertise each participant brings to the planning process.

5) Adaptable Institutions
Institutions for ecosystem management must reflect its experimental nature. Organizations, laws, policies, and management practices need to be flexible in order that they may adapt to changes in social values, environmental conditions, political pressures, available data, and knowledge. Adaptable institutions treat management as a learning process in which decisions are continuously revisited and revised, and therefore allow planning and decision-making to go forward in the face of uncertainty. At the same time, it is recognized that institutional decision-making is bounded by the currently defined legal limits of planning and management and by socio-political factors.

Ecological Society of America:

Similar elements of management are found in the Ecological Society of America's report (Christensen et al., 1996):

1) Sustainability. Ecosystem management does not focus primarily on "deliverables" but rather regards intergenerational sustainability as a precondition.
2) Goals. Ecosystem management establishes measurable goals that specify future processes and outcomes necessary for sustainability.
3) Sound ecological models and understanding. Ecosystem management relies on research performed at all levels of ecological organization.
4) Complexity and connectedness. Ecosystem management recognizes that biological diversity and structural complexity strengthen ecosystems against disturbance and supply the genetic resources necessary to adapt to long-term change.
5) The dynamic character of ecosystems. Recognizing that change and evolution are inherent in ecosystem sustainability, Ecosystem management avoids attempts to "freeze" ecosystems in a particular state or configuration.
6) Context and scale. Ecosystem processes operate over a wide range of spatial and temporal scales, and their behavior at any given location is greatly affected by surrounding systems. Thus, there is no single appropriate scale or time frame for management.
7) Humans as ecosystem components. Ecosystem management values the active role of humans in achieving sustainable management goals.
8) Adaptability and accountability. Ecosystem management acknowledges that current knowledge and paradigms of ecosystem function are provisional, incomplete, and subject

to change. Management approaches must be viewed as hypotheses to be tested by research and monitoring programs.

NMFS Ecosystem Principles Report:

This report (NMFS, 1999), delivered to the U.S. Congress, was entitled: Ecosystem-Based Fishery Management and contained eight principles:

1) The ability to predict ecosystem behavior is limited.
2) Ecosystems have real thresholds and limits which, when exceeded, can effect major system restructuring.
3) Once thresholds and limits have been exceeded, changes can be irreversible.
4) Diversity is important to ecosystem functioning.
5) Multiple scales interact within and among ecosystems.
6) Components of ecosystems are linked.
7) Ecosystem boundaries are open.
8) Ecosystems change with time.

Appendix 2

Nine tenets of management from the management literature (Appendix 1) and synthesized in this paper and summarized in Table 1.

The following is a detailed listing of the nine tenets of management from Table 1, as substantiated in this paper based on the wealth of management literature (e.g. Appendix 1). This literature (as cited in the text of this paper) presents a variety of basic principles (accepted assertions about reality, axioms, current understanding, or beliefs) and their related tenets (definition of, requirements of, or criteria for, acceptable management). This material is found primarily in the wealth of literature treating the concept of management focused on applications at the ecosystem level. The tenets may be treated as a set of criteria to judge or evaluate the adequacy of any particular management practice. They also define systemic management (e.g. Fowler and Perez, 1999; Fowler, 2002; Fowler and Hobbs, 2002) as a management scheme that meets or adheres to all nine criteria or tenets.

Tenet 1: Consistent applicability: Management must in every way be applicable at all levels of biological organization, simultaneously and consistently. Any application of management must be consistent with other applications, and management must apply simultaneously at the various levels of biological organization. For example, the harvest of biomass from individual resource species cannot be in conflict with management of the harvest of biomass from the respective ecosystems. Similarly, biomass consumption by humans from the biosphere must be guided by principles that are not in conflict with those guiding the harvest of biomass from either an individual resource species or any particular ecosystem.

Tenet 2: Accountability for complexity: Management must account for complexity/reality and each element and factor must receive importance in proportion to its relative significance. Management action must be based on an approach that accounts for reality (Appendix 3) in its complexity over the various scales of time, space, and biological organization. The context of environmental factors (e.g. ecological complexity) must be accounted for along with the elements of stochasticity and the diversity of processes, mechanics, and dynamics. The complexes of chemical and physical substances and processes as well as energetic dynamics must be taken into account, along with evolutionary processes at all levels. These factors must be given weight in decision-making that is in proportion to their relative importance and all must be dealt with simultaneously. Furthermore, we must be able to account for uncertainty, including what we cannot know, or may never know.

Tenet 3: Guidance from normative patterns: Systems, components of systems, processes, and interactions must fall within their respective normal ranges of natural variation. A core principle of management is that of undertaking actions that ensure that processes, relationships, individuals, species, and ecosystems are within (or will return to) their respective normal ranges of natural variation (based on literature as reviewed by Fowler and Hobbs, 2002) as components of the more aggregated levels of biological organization. Included are evolutionary processes, and all those involved in ecosystem dynamics, as well as physiological and embryological processes. Any form of management must apply this principle.

Tenet 4: Risk averse: Management must be precautionary and avoid risk in achieving sustainability. Management must be risk averse, exercise precaution, and achieve sustainability. Sustainability is, by definition, not achieved by any form of management that generates risk rather than minimizes it.

Tenet 5: Interdisciplinary: Management must be based on the realm of scientific studies and thereby include all disciplines. Management must be information based (Tenet 6). Guidance must be available to management in the form of useful information that enables managers to develop meaningful, measurable, and reasonable goals and objectives (Tenet 7). This information must be based on interdisciplinary approaches involving science (Tenet 6) to adhere to the principles behind Tenet 2.

Tenet 6: Information based: Management must be based upon information, including the products of scientific research, monitoring, and assessment. Management must include science (scientific methods and principles) in research, monitoring, and assessment, not only to produce the information that is used for guidance (Tenet 5), but also for evaluation of progress in achieving established goals and objectives (Tenet 7).

Tenet 7: Measurability: Management must be guided by clearly

defined and measurable goals and objectives. There must be clearly defined goals and objectives that are measurable to provide quantitative evaluation of problems to be solved and gauge progress in solving them. There must be guidelines, criteria, and standards of reference.

Tenet 8: Limited control: Management must be carried out in a way that recognizes that control over other systems (e.g. species and ecosystems) is mostly impossible. It must be recognized that complete control over other species and ecosystems is impossible. The best we can do is control human action (Christensen et al., 1996; Holling and Meffe, 1996; Mangel et al., 1996) while realizing that, even here, control remains incomplete. For example, we can better control fishing effort than we can the fish, and certainly cannot control the fact that fishing will have its consequences, many of which will be both unintended and undesirable. We can influence but not control resource populations. We can influence any ecosystem, but we cannot control them to avoid indirect changes, side effects, or secondary reactions brought about by our influence. The guidance (Tenet 7) that we need for management is guidance regarding the level of influence (e.g. harvest rate) that meets the other criteria of this list.

Tenet 9: Human involvement: Management must involve humans and their role as components of at least some natural systems. We must consider humans to be part of complex biological systems. Humans must have the option of being components of at least some ecosystems to avoid the unrealistic option of precluding human existence. Humans are not separate from, unaffected by, or free of the limits of the systems of which we are a part.

Appendix 3

Complexity

Part of the concept of expanding management to include ecosystems is the knowledge (axiom or principle) that biotic systems are complex and interconnected (Costanza et al., 1992; Christensen et al., 1996). They all have many components and involve many processes. In particular, ecosystems exist in a context, part of which is made up of, or acted upon by, other ecosystems. They involve both intrinsic and extrinsic factors (Ingram and Molnar, 1990). There are scales of time, space, and levels of organization involved in systems and their processes, dynamics, and attributes. In the end, the concept at the core of considerations of complexity in management is that complexity per se must be considered; we must consider everything (Lackey, 1995–96).

Components

The things that make up systems such as ecosystems are important, not only as determining factors in what these systems are but to the process of deciding what to do in management (O'Neill, 1989). The components of more inclusive systems involve all the living and nonliving elements of such systems (Van Dyne, 1969; King, 1993; Schramm and Hubert, 1996). Systems include the abiotic environment (Allen and Hoekstra, 1992). Species (Woodley et al., 1993) in categories such as competitors, predators, and prey (Francis et al., 1999) are part of the general diversity of ecosystems. The physical environment is part of the habitat that also has its biotic elements (Lovejoy et al., 1984; Wilcox and Murphy, 1985; Simberloff, 1988). Mineral elements make up part of the physical environment and are parts of, and required by, the biotic components (Likens, 1992; King, 1993). In addition to the material components of ecosystems, there is energy in its various forms at the core of the function of biotic systems (Bakuzis, 1969; Baron and Galvin, 1990). Individual species are represented in ecosystems by individual organisms and populations that make up biotic communities (Christensen et al., 1996). If the ecosystem is large enough, many species will be represented by several genetically distinct populations interacting as metapopulations (Sutherland, 1990).

Processes

The components of ecosystems (Clark and Zaunbrecher, 1987; Costanza et al., 1992; Davis and Simon, 1994), and entire ecosystems (Francis, 1993; Christensen et al., 1996; Mangel et al., 1996; Moote et al. (text footnote 2)), are involved in processes, interactions, relationships, and dynamics. Processes have been seen as important in the complexity of ecosystems and as factors for consideration in management (O'Neill, 1989; Noss, 1990b; Mladenhoff and Pastor, 1993; Maerz, 1994; Pickett and Ostfeld, 1995; Christensen et al., 1996: Mangel et al., 1996). More specific elements include physiological processes (Woodley et al., 1993; Christensen et al., 1996), genetic processes (Simberloff, 1988; Vrijenhoek, 1989; Woodruff, 1989; Policansky and Magnuson, 1998; NRC, 1996, 1999), trophic flow (Ulanowicz, 1992), extinction (Terborgh, 1974; Wilcox and Murphy, 1985; Norton, 1987; Myers, 1989; Reed, 1989; Westman, 1990; Gaston and Blackburn, 2000), population variation, predation (Orians, 1990), and diseases (Pimm, 1991). The dynamics of populations are involved (Baron and Galvin, 1990; Woodley, 1993). In the interactions among species there is influence on composition and function of ecosystems studied as the keystone effect (Westman, 1990). Other processes (Christensen et al., 1996) include photosynthesis (or primary production, Woodley, 1993), decomposition (Woodley, 1993), the hydrologic cycle, evapotranspiration, geomorphic processes and erosion, and other soil or below-ground processes (Baron and Galvin, 1990). The bio-geochemical/energetic concepts of the "physiology" of ecosystems has been a long-standing view of the function of ecosystems with their flux of nutrients and mineral elements (e.g. Bakuzis, 1969; Loucks, 1985; O'Neill et al., 1986; Ehrlich, 1987; Baron and Galvin, 1990; Likens, 1992; Woodley, 1993; Moote et al. (text footnote 2))—all part of internal ecosystem function (Christensen et al., 1996). All of the components are involved in interactions, processes, and evolution (O'Neill, 1989; Mangel et al., 1996) sometimes seen as components of diversity (Noss, 1990b). In regard to the genetics of species within ecosystems and evolutionary dynamics there are a number of recognized processes (Terborgh, 1974; Ehrlich, 1987; Orians, 1990; Sutherland, 1990; Apollonio, 1994; Christensen et al., 1996). These include extinction (Terborgh, 1974; Fowler and MacMahon, 1982; Lovejoy et al., 1984; Wilcox and Murphy, 1985; Myers 1989; Reed 1989; Orians 1990; Westman 1990), biotically controlled evolution, dispersibility (dispersal or mobility, including invasions and introductions (Terborgh, 1974; Westman, 1990)), specialization, mutualism, and coevolution (Norton, 1987; Westman, 1990; Thompson, 1994). Individual organisms are among the components of ecosystems, and their behavior and physiology (Christensen et al., 1996) count among the processes within ecosystems.

At the more general level, ecosystems themselves have behaviors and properties that involve dynamics; ecosystems themselves change (Pfister, 1993; Christensen et al., 1996). However, one of the processes of ecosystems is that of their homoeostatic behavior (Apollonio, 1994) or their tendency to exhibit pattern and attributes. In other words, such systems have a tendency to exhibit variation, or change, that is confined to within certain limits to show pattern (Fowler and Hobbs, 2002). Because of the complexity of ecosystems, especially the interrelated nature of the components (Costanza et al., 1992), there are repercussions stemming from the influence of any species. These complex processes are often referred to as ripple effects (Wilcox and Murphy, 1985). Out of all of this emerges the novelty of ecosystems and their components (Costanza et al., 1992).

Scale: Temporal, Spatial, Hierarchical

That management must consider context and scale is given the status of a separate tenet by Christensen et al. (1996) and is mentioned in many papers on management (Moote et al. (text footnote 2)). The need to account for spatial scales (Steedman and Haider, 1993) and temporal scales (Noss, 1993) is extended to that of organizational complexity and hierarchical context (King, 1993; Apollonio, 1994; Grumbine, 1997). Complexity is involved in the fact that temporal scales extend from the immediate to the evolutionary and geological. The need to account for long-term temporal scales is often emphasized (e.g. Lee, 1993a; Schramm and Hubert, 1996; Moote et al. (text footnote 2)). Large geographic scales are also emphasized (Schramm and Hubert, 1996). These extensions are often mentioned in regard to problems identified with attempts to take small-scale approaches to the exclusion of consideration of long-term, global, or more inclusive levels of biological organization. As with moves to extend single-species approaches to include ecosystems, these are not meant to move from (abandon) one to embrace another approach but to expand management in such a way that issues of all scales are included whether temporal, spatial (Schramm and Hubert, 1996), or hierarchical (Costanza et al., 1992). Extensions to higher levels of organization are exemplified by work on metapopulation analysis and the need to consider such issues in management (e.g. Simberloff, 1988).

The issue of scale brings on the matter of control (Tenet 8). An ecosystem represents the cumulative effects of other elements of a species' environment. As such, the higher (more complicated, more inclusive) levels of organization are seen as controlling of their components (Salthe, 1985; O'Neill et al., 1986; Koestler, 1987; Costanza et al., 1992; Apollonio, 1994; Wilber, 1995; Fowler and Hobbs, 2002) in ways that are of greater importance than the effects of just one element at the same level. Thus the population of one species is more regulated by an ecosystem than it is by any one population of another species within the same ecosystem.

Ecosystem attributes

Despite the fact that ecosystems change (plus the fact that their components exhibit a great deal of dynamic properties) structure and pattern are inherent properties of ecosystems, some of which are emergent from the complexity of nature, and many of which are referred to as macroecological patterns (Brown, 1995; Gaston and Blackburn, 2000). Various measures of diversity provide a metric of one such attribute (e.g. species numbers). Most such attributes are viewed as important characteristics for consideration in management (e.g. Wilcox and Murphy, 1985; Orians et al., 1990; Westman, 1990; Noss, 1993; Woodley et al., 1993; Davis and Simon, 1994; Noss and Cooperrider, 1994; Wood, 1994; Naiman et al., 1995; Moote et al. (text footnote 2)). Measures of diversity are not restricted to taxonomic units and can include genetic or functional considerations—all seen as important in management (Orians et al., 1990; Westman, 1990). Other attributes seen as important in both the characterization of ecosystems and management involve trophic level, food web structure, distribution of matter and energy, and range distribution of populations (Terborgh, 1974; Baron and Galvin, 1990; King, 1993; Christensen et al., 1996). The composition of ecosystems, in this regard, is often recognized as important to consider and viewed as part of the integrity of ecosystems (Noss, 1990a; Noss, 1993; Pfister, 1993; Davis and Simon, 1994).