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New Pathways for Conservation Science

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In collaboration with his graduate students, he continues his work on imperiled species. Their focus is on changes in land-use and management practices that promote the conservation of species but still allow substantial levels of human-use. This research focuses on land-use practices on both public and private lands and tries to emphasize positive incentives to promote the conservation of nature. He is confident that science can make significant contributions to the resolution of many conservation problems. However, he believes that science alone is insufficient – solutions require all individuals to behave in a way consistent with their long-term stewardship responsibilities.

New Pathways for Conservation Science

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New Pathways for Conservation Science

Abstract

In the following essay, I address several issues relevant to the conservation of our natural heritage. Specifically, I make the argument that conservation biology – the scientific discipline with an explicit goal of conserving biological diversity – must embrace other disciplines to achieve its objectives. Collaborations with economic, political, and social scientists, for example, are essential to reach a balance between expanding human dominance of all ecological systems and the protection of species and their habitats. Several new, or existing, pathways for acquiring new knowledge must be better traveled: 1) Scale up from individual, population, and species level studies to include inferences to the ecosystem scale. 2) Develop an accelerated research program to better understand the importance of species to the production of ecological goods and services valued by humans. 3) Include human demographic, social, political, and economic factors as design variables in research studies. 4) More fully engage with policy makers in explaining the relevance of conservation science to human welfare and quality of life. And, 4) Re-examine the academic curriculum for graduate student education in ecology to better train the next generation of interdisciplinary "problem solvers."

Introduction

During the summer of 2002 in Canterbury, England, Dr. John Lawton, well-known ecologist and former president of the British Ecological Society, spoke at the annual meeting of the Society for Conservation Biology. The gist of his plenary talk was that conservation biologists were winning an occasional battle in their effort to conserve biological diversity, but for the most part were losing the war. The war was being lost on a number of fronts: the number of species at risk of extinction or experiencing significant reductions in geographic range was increasing; the area and continuity of habitat to support these species were in decline; and the

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This talk is the fifth lecture in the second year of our Faculty of Forestry Jubilee Lecture Series.

threats to species were increasing in number and magnitude. This was occurring despite the fact that scientific evidence documenting these losses was accumulating at a rapid rate. In one sense, conservation scientists were doing their job – they were focusing their studies on species and habitats at risk and were offering possible solutions to reverse these declines. However, the scientists were largely being ignored by policy makers.

To be more effective in addressing threats to our natural heritage there is a clear need for more and better sustained funding. Beyond the predictable plea for more funds, however, Dr. Lawton called for a fundamental shift in how conservation biologists practiced their discipline. Because conservation issues are not just about biology, he emphasized a need to reach out to other disciplines – hence the change from conservation *biology* to conservation *science* in my title – and for conservation practitioners to more fully engage in policy formulation.

Dr. Lawton's address was a strong stimulus for subsequent discussion – some in favor of his thesis and some strongly opposed. The theme of his talk, however, resonated strongly with me. Over the last few years I had come to recognize that my own work – done in collaboration with many devoted and intelligent colleagues and students – was largely irrelevant if gauged by the standard of informing land-use policy. Outside the realm of fellow academics and researchers, it mattered little whether I found convincing evidence that a species was being adversely affected by land-use practices, or I had contributed to improved methods to assess the impacts of land management on wildlife. In the area of biodiversity protection, translating scientific findings into meaningful changes in land-use policy was generally not occurring. In the U.S., many policy makers were either indifferent to scientific studies documenting increasing threats to biodiversity, or they were openly hostile to such findings.

Unless we are content to conduct scientific studies that are considered irrelevant by the majority of policy makers, we must ask ourselves a number of probing questions: Are our studies relevant to how humans interact with and transform the landscape? Do our scientific studies suggest a significant risk to the welfare of future human generations if current land-use practices are continued into the future? Do conservation scientists bear any responsibilities to inform, or comment on, current land-use policies? Should conservation scientists be more engaged in policy relevant research? If the answer to the last question is yes, how do they engage and retain their scientific objectivity?

What Is the Evidence for the Decline of Biological Diversity?

At this time, the available scientific evidence suggests that all major ecological systems are human-dominated (Vitousek 1997, Sanderson *et al.* 2002). By that, I mean that the major driver of change in species composition, landscape structure, and ecological processes (e.g., hydrological cycles, nutrient cycling, and disturbance events) is human transformation of the landscape. As a consequence of this behavior, many plant and animal taxa in all ecological systems – terrestrial, marine, and freshwater – are currently in decline or at risk (Pimm *et al.* 1995, Pimm 2001, Wilson 1999). For example, human beings directly or indirectly expropriate 40% of all terrestrial plant growth, over one quarter of all marine primary production, and 60% of accessible freshwater (Pimm 2001). The impact of humans on the ecological systems they occupy and exploit can be measured as the product of per capita consumption and population size (Ehrlich and Ehrlich 1981). This measure is increasing globally but the relative importance of the factors varies geographically. In developing countries population growth is the dominant factor, but in developed countries (i.e., western Europe and North America) it is per capita consumption.

Peter Vitousek and others (Vitousek *et al.* 1986) refer to a causal graph that illustrates the pervasive effect of human behavior on ecological systems (Figure 1). Two main behaviors, industry and agriculture, give rise to multiple stresses including changes in atmospheric chemistry, altered biogeochemical cycles, novel toxins, land transformations, and invasive species. These stressors act directly or indirectly through other agents, to compromise ecological integrity. Stressed ecological systems have several characteristics in common (Gunderson and Holling 2002). These include simplified food webs, homogenization of the landscape and conversion to unnatural states, high nutrient and energy inputs, resource exploitation in excess of the systems regenerative capacity, and the loss of biological diversity.

Two recent studies document the intensity and scale of human dominance of the earth's ecological systems, suggesting an urgent need to redefine our relationship with the natural world. Sanderson *et al.* (2002) estimate the size of the human footprint by creating a global map of human influence on the earth's surface. They used four data sources as proxy measures of human influence including population density, land transformation, accessibility (i.e., road infrastructure), and the extent of the electric power network. They find that 83% of the land's surface, and 98% of the area where it is possible to practice intensive agriculture, is

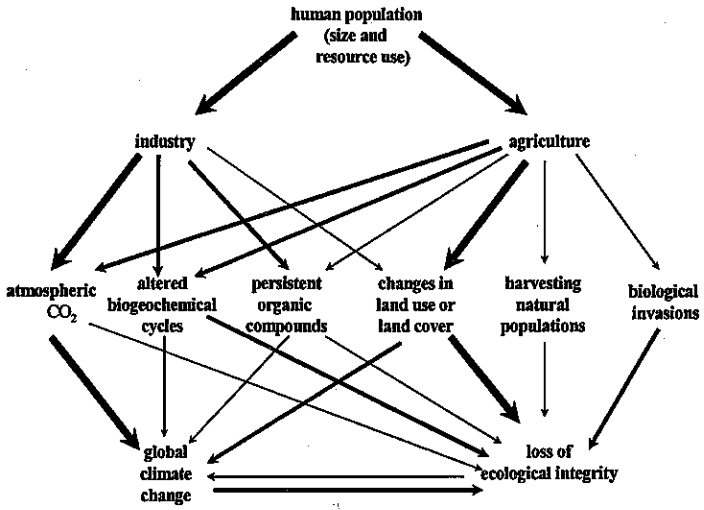

Figure 1. Illustration of human dominance of the earth's ecosystems (after Vitousek 1994).

directly influenced by human beings. However, the majority of the world (60%) lies between the extremes of natural "wildness" and complete human transformation. This large area presents an exciting opportunity for conservation scientists to develop resource management practices that lead to long-term sustainability. Even though human impacts will continue to be the dominant drivers of biological systems, human influences are not necessarily negative. In fact, those few locations where the human impact is great but species and natural systems still persist should be focal locations for intensive study by conservation scientists.

In a complementary, but independent, analysis (Wackernagel *et al.* 2002) estimate the ecological footprint of the human economy. This investigation correctly recognizes that the human economy depends on the earth's natural capital which provides all ecological services and natural resources. The ecological footprint is measured as the area of biologically productive land and water required to produce the resources consumed and to assimilate the wastes generated by humanity. To compute the size of the footprint, the authors combine information from six measures of human activity that require biologically productive space. These activities include agricultural; grazing domestic animals; harvesting for timber and mining for fuel; marine and freshwater fishing; human infrastructural development; and burning fossil fuels. These activities

are assigned area equivalents based on their actual area weighted by relative measures of productivity. Beginning in 1961, the authors compare humanity's demand for natural capital to the earth's biological productivity. Their results suggest that human activities have exceeded the earth's regenerative capacity since the 1980s with the overshoot exceeding 20% by 1999.

These and related studies are not without their critics (e.g., Fitzsimmons 1999, Lomborg 2001). Ecologists are not infrequently accused of crying "wolf" and presumably for that reason are often marginalized in policy debates over management of natural resources. I have not done a comprehensive analysis of recent publications addressing the state of various species or ecosystems, but my strong impression from the primary literature in ecology is that the weight of evidence suggests an accelerating trend towards the degradation of ecosystems and the loss of biodiversity. Here again, the critics have weighted in suggesting a publication bias in favor of doom and gloom stories about ecological systems. I am not aware of any credible studies of a publication bias and therefore cannot respond directly to this claim. However, when I reflect on the current state of species and ecosystems that I have been familiar with since I was a young child, my confidence in the published literature as a credible unbiased source of information is reinforced.

What Have Conservation Biologists Been Studying?

If the trajectory of change has been towards the simplification and transformation of ecosystems with a concomitant loss of species, what have conservation biologists been studying? They have been studying the biological issue relevant to conservation practice. For example, during the last two decades great progress has been made in methods of identifying species at risk; development of sophisticated quantitative methods to assess species viability; principles of reserve design including their size, spacing and landscape context; exploring the effects of changes in habitat geometry and its effects on population dynamics; the genetic and demographic risks arising from small population size; and improved methods for captive propagation of endangered species.

These advances in knowledge are significant and reflect a field of study that is mature and disciplined. Clearly, many intelligent and creative scientists participate in the practice of conservation biology. Despite evidence for significant progress, however, much of conservation biology has been reactionary and crisis driven. This is not unexpected in a science that is poorly funded – researchers will direct their

research proposals to where the money is. In the absence of a large research program with a specific focus (e.g., the human genome project, unmanned exploration of Mars) conservation biology often appears as an eclectic collection of individual studies lacking a common theme. In my opinion, one research theme that should have high priority is to view conservation issues from a hierarchical systems perspective. The vast majority of studies in conservation biology have focused at the individual or species level. For example, many researchers have addressed questions such as what is the current status and geographic distribution of species X, what is its temporal trend, and what are the factors correlated with its temporal trend? Some have looked at conservation from a guild or species assemblage perspective, but such studies are rare. Few researchers have attempted to scale up from the species level to make inference to the effects of species loss or decline on the ecosystems to which they belong.

In addition, many practitioners have been myopic in their views of conservation biology focusing on "biology" to the exclusion of social and economic factors that are often the ultimate factors putting species at risk. I do not wish to be too critical if for no other reason than that I have been guilty of this same myopia. Our avoidance of including social and economic factors as design variables in our studies is understandable. Many of us began our studies of natural systems with specific direction from our advisor and committee members to avoid study areas that were too disturbed by humans. There was a sense that if we did not conduct our research in somewhat pristine areas that any insights we gained from our research would be biased, misleading, or site specific. Thus there was an explicit or implicit message to exclude any possible cause-effect relationships arising from the behavior of human beings.

Both of these shortcomings can be demonstrated from my discipline, wildlife biology, and from my own work. Much of wildlife biology focuses on understanding and documenting the proximate factors correlated with population dynamics (Figure 2). These include factors such as habitat loss and fragmentation, disease, harvest rates, levels of predation, and invasive species. Associated with these factors are a set of penultimate factors that are less often the focus of research. These include land use change and conversion, pollution and toxic substances, illegal harvest and poaching, and human harassment (e.g., bright lights, noise level, motorized vehicles). Underlying the penultimate factors is a set of ultimate factors that are just beginning to be explicit variables in research conducted by wildlife and conservation biologists. These include, for example, the economic decisions that lead to habitat loss and fragmentation, a legal system that fails to implement the laws that restrict the addition of pollutants and toxins to our environment, a political system that promotes the exploitation of nature more than its stewardship, and a social system that tolerates all these factors.

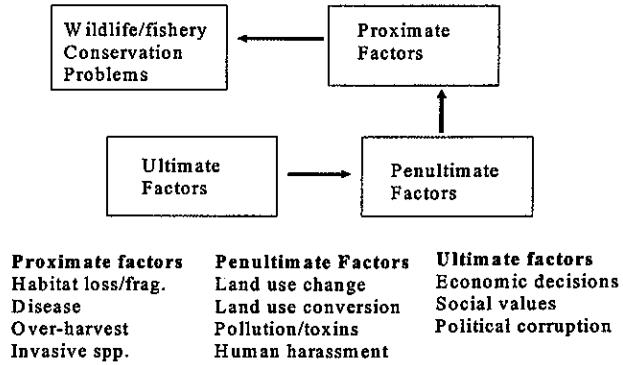

Figure 2. Traditional questions asked in wildlife ecology.

In the following discussion I will focus on three topics relevant to establishing new pathways for conservation biology. These include two research agenda topics: linking species more explicitly to ecosystem dynamics and outputs; and explicitly incorporating human-nature interactions as explicit design factors in our research studies. The third topic addresses the science-policy interface and how conservation scientists can best participate in a dialogue with the public. Key goals of this dialogue are to encourage people to think about the aspects of nature they most value, to understand that the choices they make have the potential to compromise these values, and to articulate the role that conservation science can play in finding ways to balance these inescapable tradeoffs.

Linking Species to Ecosystems

The title of this section is also the title of a book that arose from a 1994 Cary Conference at the Center for Ecosystems Studies in upstate New York (Jones and Lawton 1995). One goal of that conference was to stimulate a new research agenda that addressed the question "What do species do in ecosystems?" (see Lawton 1994). Many events, ranging

from pragmatic to purely scientific, may have stimulated this question. For example, how to better answer questions from the public as to why their tax dollars should be devoted to species conservation and habitat acquisition when, in their minds, more pressing needs where going unmet. Also, the discomfort that ecology professors feel when asked by their students why they should care about the fate of a particular species, or why they appeared so concerned about the loss of biodiversity. And, the many scientific studies, both theoretical and empirical, trying to predict the consequences of species addition and deletion "experiments" that have come to recognize that the long-term consequences of such events are highly uncertain.

There are many reasons to conserve species. For example, many species are harvested for food or hunted for sport. Since markets exist for these species it is relatively straightforward to compute their value to humans in traditional economic terms. However, for the majority of species, conventional commodity markets do not exist and their value to society is much more difficult to measure. For example, species have great value to people for religious, spiritual, and aesthetic reasons. Most people would admit that their lives would be of lesser quality if they could not directly experience wildlife and natural landscapes or know that such existed. Economists have developed indirect ways of estimating their value based on willingness to pay and other contingent valuation methods. However, these methods are much criticized by mainstream economists. The reality is that it is impossible to assign value, at least as measured in economic terms, to the vast majority of species.

Given the human dominance of most ecological systems, coupled with the fact the human-centric value of most species is unknown, conservation scientists have the opportunity to address a socially relevant and scientifically challenging problem by attempting to answer the question, "What do species do in ecosystems?" To answer this question will require conservation scientists to scale up both in time and space. The traditional set of questions addressed in wildlife ecology (for example, Figure 2) are currently insufficient. To address the ultimate causes of species declines often requires the researcher to scale up – a pathway that often leads to human influence.

This idea has been captured in a simple conceptual model developed by a National Research Council Panel on the future of ecosystem science (NRC 2000; Figure 3). Their model can be interpreted as a causal graph that, when followed in reverse, leads from biodiversity declines to changes in land use and land cover to human activities – all occurring in the context of a changing climatic regime.

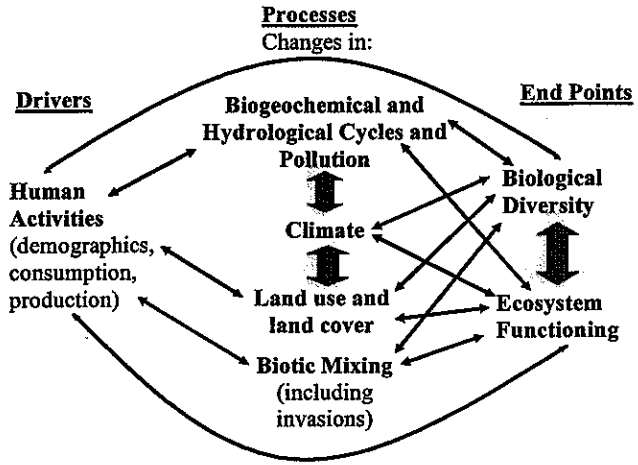

Figure 3. Conceptual model of global change due to human influence (after NRC 2000).

Some significant progress has been made in addressing the importance of species – the question of what species do can be partially answered in some systems and for some species. Much of the scientific evidence accumulated to date has recently been summarized in a book edited by Peter Kareiva and Simon Levin (Kareiva and Levin 2003). For the most part, however, contributions to this volume are case-specific, inconclusive in that the functional role of most species remains unknown, and fail to find any consistent generalities that would allow "important" species to be identified a priori.

In addition to asking "What do species do in ecosystems?", it is also useful to ask "What do species tell us about ecosystems?" That is, it is important to broaden the question a bit and expand beyond just the functional role of species to ask if there are categories of species that are useful for assessing the state of ecological systems occupied by humans. In this case, several useful categories of species have been identified including:

1. **Indicator species:** "An organism whose characteristics (presence or absence, population density, dispersion, reproductive success) are used as an index of attributes too difficult, inconvenient, or expensive to measure for other species or environmental conditions of interest" (Landres *et al.* 1998). Indicator species can be further broken down into three categories (Caro and O'Doherty 1999).

- *Early warning indicator:* Provides an early warning of a stressor acting on a key ecosystem process. For example, changes in lichen communities in forest ecosystems may act as indicators of stress arising from atmospheric pollution.
- *Population surrogate indicator:* Species whose status and trend are indicative of the status and trends of other species.
- *Biodiversity indicator:* A species, or more commonly a taxonomic group, that acts as a surrogate for a number of poorly known taxonomic groups.

2. **Umbrella species**: A species that needs such large areas of habitat that managing for its viability addresses the viability concerns of numerous other species with similar habitat but smaller area requirements (after Wilcox 1984). The principal requirement of an umbrella species is that its range is large compared to sympatric species. Many large-bodied animals are candidate umbrella species – for example, bison in prairie ecosystems. (Also see Andelman and Fagan 2000, and Fleishman *et al.* 2000).
3. **Keystone species**: Species which significantly affect one or more key ecological processes or elements to an extent that greatly exceeds what would be predicted from their abundance or biomass (Mills *et al.* 1993, Power *et al.* 1996). Sea otters prey strongly on the herbivores that consume kelp forests. Diverse kelp forests, in turn, support diverse communities of vertebrates and invertebrates. (Also see Fauth 1999).
4. **Strong interactors**: A species whose dynamics are affected by, or greatly affect, the dynamics of other species in the community (Emlen *et al.*, 1992). Energy-maximizing predators in freshwater aquatic ecosystems often exert strong top-down control on the structure and composition of their prey communities.
5. **Link species**: A species that occupies a key position in a food web and efficiently transfers energy and matter between trophic levels. Prairie dogs in grassland ecosystems efficiently convert primary plant productivity into animal biomass. Prairie dog biomass, in turn, supports a diverse predator community. These are similar to the bottom-up members of food webs discussed by Jordan *et al.* (1999).
6. **Ecological engineers**: Species that directly or indirectly control the availability of resources to other organisms by causing physical state changes in biotic or abiotic materials (Jones *et al.* 1994, 1997). Beavers alter and restructure riparian habitats and greatly increase the diversity of both plant and animal communities as a consequence.
7. **Species that belong to non-redundant functional groups**: See discussion in Schulze and Mooney (1994).

These are categories of species whose behaviors structure ecological systems, affect the flows of matter or energy in these systems, provide opportunities for the support of additional species, or provide a disproportionate amount of information about the state of the systems. Identifying additional categories of species, and placing species within these categories, is a logical first step to linking species to ecosystems.

It is clear that much work remains to be done. Theory (e.g., Holling 1992; Gunderson and Holling 2002) suggests that ecosystem properties constrain and drive the dynamics of species. Species in turn are predicted to give rise to, and change, the properties of ecosystems. If we contrast the properties of ecosystems with species (Table 1) we see many similarities providing weak support for these theoretical arguments. However, there is a big gap between theory and application in the management of ecological systems (Gunderson *et al.* 1995). Drawing insights from theoretical generalities to guide on-the-ground management practices remains very difficult.

Table 1. Contrasting properties of ecosystems and species.

Attribute	Biological Population	Ecological System
Dynamic and non-equilibrial	Yes	Yes
Dependent on natural disturbances	Yes	Yes
Show time lags following disturbance	Yes	Yes
Show non-linear dynamics and thresholds	Yes	Yes
May occupy alternative stable states	Yes	Yes
Levels of resilience are poorly known	Yes	Yes

Incorporating Human Factors in Conservation Science

There are at least two distinct ways that humans can be viewed as explicit factors in resource conservation – as causative factors in understanding the dynamics of natural populations and as constraints on the management of ecological systems. To understand causation, we

need to include human behaviors as independent variables in our research studies. The design of research investigations is usually a required course for students in the natural sciences. Professors in fishery and wildlife biology emphasize the need to clearly identify an interesting question, restate that questions as a research hypothesis, and finally recast the question into a statistical hypothesis. At this point the task is to identify all those factors that may influence the value of the response variable. It is at this stage that we need remind our students (and ourselves) to break from the traditional practice of excluding human factors from our experimental design.

Humans should also be viewed as the dominant driver of ecological systems because their uses often constrain possible conservation objectives. Currently, ecosystem management (EM) is the popular paradigm that explicitly incorporates human values and human uses as legitimate components of ecological systems (Grumbine 1994). A number of authors have assembled lists of the attributes of EM viewing different degrees of human dominance as points along a continuum. However, a single continuum may confound different dimensions of EM that are actually somewhat independent. Bolger and others (unpublished) divide EM into a three-dimensional decision space including spatial scale, ecological complexity, and human values (Figure 4). The ecological complexity scale incorporates different levels of the biological hierarchy; the spatial axis is a qualitative scale of increasing geographic scope; and the values' scale incorporates varying human objectives that guide EM. Choices within the decision space are made collaboratively by stakeholder groups and the dimensions of the decisions are made explicit. This conceptual model is useful because it directly acknowledges how human values drive the management process and the extent of human dominance. It also illustrates the extent of environmental impacts – the higher an activity appears in the biological hierarchy the greater the potential ecological effects.

The Interface Between Conservation Science and Public Policy

Given the magnitude and continuing growth of the human and ecological footprint, and the relationships captured in Figures 1-3, it is clear that an understanding of the dynamics of plant and animal species requires simultaneous study of the dynamics of human behaviors. Many prominent ecologists have written on this topic in recent years (e.g., Peterson, 2000, Holling 2001, Ludwig, *et al.* 2001, Walker *et al.* 2002) and the need for scientists to more fully engage with policy makers has

been a unifying theme of these papers. However, many policy makers are indifferent to scientific evidence no matter how compelling – they are only responsive to majority public opinion. But it is still unclear how to get the attention of the public.

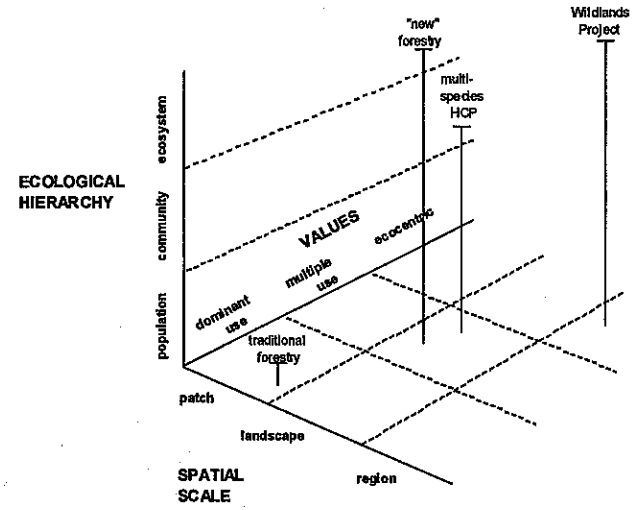

Figure 4. The three axes of ecosystem management (spatial scale, ecological hierarchy, and human values) with examples of different EM approaches plotted in three dimensional space (after Bolger *et al.*, unpublished).

Currently in the United States environmental regulations that maintain minimum standards for air and water quality, provide protection of biological diversity on public lands, and safeguard wetlands and first order streams are being relaxed. At a time when the scientific evidence documenting the loss and decline of species and their habitats has never been more compelling, essential protections are being reduced or eliminated. However, these issues seldom make the front section of the newspaper, are not discussed on the national news, and are generally "off people's radar screens." Within recent years, it has been difficult to raise these issues to the level of a national debate – for example, a recent public poll in the U.S. ranked environmental issues 13th out of 14 issues considered. Currently the problem is exacerbated because people are preoccupied with the possibility of war with Iraq and the downturn in the U.S. economy. Under these conditions, it is difficult to find a sympathetic ear for the plight of nature.

Some ecologists, in collaboration with economists, have attempted a new approach to gain the public's attention. That is, they are enumerating the environmental goods and services that humans acquire from intact ecosystems, but that are not traded in the market place (see Daily 1997; Daily and Ellison 2002). The gist of their argument is that these are essential services for human welfare but they have no technological substitute, or if a substitute exists it is prohibitively expensive. Both the expertise of the ecologist and the economist is required. The ecologist must exhaustively identify the goods and services provided by nature, issues of resource scarcity and slow renewal, and how these products are being affected by human land use. Once identified, the economist must make sure the price is correct, that discount rates reflect renewal rates, and that supply and demand is accurately estimated.

It is generally accepted by most conservation scientists that intact ecosystems are essential for human welfare. We may debate how many species are required to provide these outputs, or how much functional redundancy is needed, but the consensus is that we cannot live in the absence of sustainable ecosystems. To gain the public's attention and to get to the point where the public accepts this fact may require adopting a common measurement scale to assess value. Translating nature into dollars is appalling to many conservation scientists. However, when you are losing the war for species conservation more drastic measures are required. In the context of increasing human population size and per capita consumption, it is probably naïve to think that appeals to the aesthetic or spiritual values of nature will carry the day.

In addition to initiating collaborative studies with economists there are many other disciplines that could aid the cause of biodiversity conservation. These include political scientist who are more skilled than most biologists in engaging in fruitful discussions with politicians and who could communicate the insights from our studies in less threatening ways. Certainly, social scientists, particularly those with expertise in conflict resolution, could help us in addressing the immediate needs of imperiled species found mostly on private land. And, given the extent of degraded terrestrial and aquatic ecosystems collaborations with engineers in large scale restoration projects will also be essential.

Summary Recommendations

My key recommendation is that the evidentiary foundation arising from conservation research not be restricted to, or even primarily focused on, conservation biology. The discipline needs to be expanded to explicitly include human demographic, social, and economic factors. This broader discipline is *conservation science*. To accomplish this transition, several new pathways of conservation science need to be traveled.

- Scale up from individual, population, and species level studies to include inferences to the ecosystem scale. This is the scale at which humans interact with and affect the environment.
- Develop an accelerated research program to better understand the importance of species to the production of ecological goods and services valued by humans. This information will allow conservation scientists to better predict the consequences of species additions or deletions and their effects on sustainability.
- Include human demographic, social, political, and economic factors as design variables in research studies. This will allow inference to ultimate cause-effect relationships to better understand patterns of species decline and increase.
- More fully engage with policy makers in explaining the relevance of conservation science to human welfare and quality of life. Propose collaborative partnerships to solve common problems.
- Re-examine the academic curriculum for graduate studies in natural resources to see if it possible to better train the next generation of conservation practitioners.

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