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Ecology, Conservation, and Public Policy

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■ **Abstract** A new sense of urgency about environmental problems has changed the relationship between ecology, other disciplines, and public policy. Issues of uncertainty and scientific inference now influence public debate and public policy. Considerations that formerly may have appeared to be mere technicalities now may have decisive influence. It is time to re-examine our methods to ensure that they are adequate for these new requirements. When science is used in support of policy-making, it cannot be separated from issues of values and equity. In such a context, the role of specialists diminishes, because nobody can be an expert in all the aspects of complicated environmental, social, ethical, and economic issues. The disciplinary boundaries that have served science so well in the past are not very helpful in coping with the complex problems that face us today, and ecology now finds itself in intense interaction with a host of other disciplines. The next generation of ecologists must be prepared to interact with such disciplines as history, religion, philosophy, geography, economics, and political science. The requisite training must involve not only words, but core skills in these disciplines. A sense of urgency has affected not only ecology but other disciplines that influence environmental problems: they are undergoing a similar transformation of their outlook and objectives.

INTRODUCTION

More than any previous generation, the current generation of ecologists is concerned about applications of their work to society's problems. Since the first Earth Day about 30 years ago there has been a change in the public perception of environmental problems and a corresponding growth in the sensitivity of ecologists to issues of public policy (Brown 2000, Kaiser 2000, Padilla & Gibson 2000). Berkes (1999) reiterates the question of Roszak (1972, p. 404), "Which will ecology be: the last of the old sciences or the first of the new?" Such hopes and expectations place a heavy burden on ecologists. Furthermore, the scope and setting of ecology has changed in the last three decades. Mangel et al. (1996) summarized these changes as developments in (*a*) ecological and biological understanding,

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(*b*) the combination of economics and ecology, (*c*) institutions and policy, and (*d*) technology and methodologies.

There are two themes in our review. The first is scientific uncertainty in ecological problems and its influence on relations between ecologists and policy makers. Uncertainty in ecological knowledge causes difficulties when this knowledge is used for regulatory purposes. This effect may be compounded when regulatory agencies adopt policies advocated by industries that are being regulated. Many scientists experience such phenomena when they work for government agencies or when they attempt to influence public policy. The second theme is an appreciation of insights from other domains of knowledge; here we cannot be exhaustive, but hope to provide entry into the relevant literature. Clearly scientific understanding, and particularly ecological understanding, is an important tool for dealing with environmental problems. Now it is also clear that scientific knowledge will never be enough. Somehow that knowledge must be integrated with political, economic, social, ethical, and religious insight, and tempered with respect for human dignity and for the biosphere. For example, although the modern world has characterized indigenous and traditional peoples as "primitive," some of them have (or had) highly evolved social and religious systems that promoted sustainable use of natural resources for hundreds and thousands of years (Bodley 1990). We believe that ecologists can be effective in conservation efforts only if they understand and appreciate the social and ethical aspects of conservation. Because this wider understanding is at the heart of an effective approach to conservation, we first provide examples illustrating the issues.

Environmental Problems are "Wicked"

Problems such as conservation of world forest resources, conservation of endangered and threatened species, and global climate change are not merely ecological or scientific. They involve a host of traditional academic disciplines that cannot be separated from issues of values, equity, and social justice. Whether our progeny live in a world at war or at peace may hinge on equitable resolutions of environmental problems (Homer-Dixon 1991, 1994; Homer-Dixon et al. 1993). Rittel & Webber (1973) defined "wicked problems" as those with no definitive formulation, no stopping rule, and no test for a solution. Solutions are judged good or bad instead of true or false, and there will likely never be a final resolution of any of these problems. Each wicked problem is unique and defies classification. Roe (1998) calls these problems "truly complex" or "complex all the way down." Funtowicz et al. (1999) call such problems "post normal," characterized by "radical uncertainty" and a "plurality of legitimate perspectives." They characterize analysis of complex systems as "feeling the elephant," in analogy with the classic story of the blind men and the elephant. The same analogy is used in the context of koala conservation in Clark et al. (2000, p. 699). Maddox (2000) notes that "the best environmental policy depends upon how you frame the question." These problems will not be dealt with by optimizing or managing anything (who manages climate change?); there are no experts for such problems, nor can there be. Dealing with these problems involves much more than ecology and science; it requires an understanding of how economic and social factors interweave with ecological and evolutionary science. The construction of effective approaches may require specification of mechanisms, processes, and parameters that may not be accessible. Here are some examples of such problems.

Forests

The World Commission on Forests and Sustainable Development was established by a group of distinguished world leaders following the Earth Summit in 1992. The Commission worked for five years, holding hearings around the world. Their report (WCFSD 1999) emphasizes that problems of forest conservation cannot be separated from problems of equity and of governance:

> [p. 59] ... forest dwelling communities can be found in all types of forests, in every geographic region of the world. Everywhere they are beset by similar forces: loggers, ranchers, and others moving onto their lands; erosion of their traditional rights of access and use; displacement of their homes; erosion of their livelihoods; ignorance of their values, their historical custodial functions, their accumulated intellectual property; disregard of the authorities; often persecuted by the powers that be and the politically strong. These forces are likely to become intensified as the world gets more crowded, as the demands on forests increase, and as forest capital further declines. Yet there was no evidence in any region of a constructive and compassionate movement on the part of political leaders to prevent these abuses and protect the poor and politically weak, despite the fact that we are in the United Nations Decade for Indigenous Peoples. [p. 60] It is a travesty of justice that the rights of such communities—communities which via their custodial services subsidize the world—are not secured, while financial fortunes from exploitation of a country's forest capital accrue to private corporate interests and government treasuries, to merchants and middlemen.

Very similar messages with abundant detail appear in Bodley (1990). Applications to rangeland appear in Busby & Coz (1994). Robinson (1993) notes that by not recognizing the conflicts and contradictions inherent in conservation and development, one can reach simplistic and inappropriate conclusions; that even "sustainable development" will lead to loss of biological diversity; and that "carrying capacity is not an ecosystem characteristic, but is defined for the population of a given species" (p. 23). See Cohen (1995) for a general discussion of the meaning of human carrying capacity.

Endangered Species

Various institutions have attempted to ensure the survival of endangered species by establishing protected areas. These are generally far too small for many species, and they cannot cover more than a small fraction of species under threat. Furthermore, the areas that are established often cannot be protected because of incursions by people living nearby and extensive forest removal and road building in adjoining areas. In response, community-based conservation has been attempted. Many of these efforts have also failed: the local communities that must be involved in conservation efforts are often powerless to resist exploitation by industries, governments, and the military. They may see their traditional use-rights curtailed and their legal status altered to "poacher." Although at first sight the problem of conservation seems to be a scientific one, it may primarily be a problem of governance and of equity (Clad 1988, Goodland 1988, Wells et al. 1999, Wells & Brandon 1992, Brandon 1997, van Schaik et al. 1997, Sanderson & Redford 1997) or population (Mangel et al. 1996). Sometimes it is possible to involve local populations in conservation successfully but "to devise policies that lead to resource conservation through indigenous management, we believe it will be necessary to understand the distinctive features of the foraging *economy*, as a matter of behavior with practical consequences" (Winterhalder & Lu 1997, p. 1362). It is worth noting that, in some cases, individuals of the species being protected cannot even be easily identified (McElroy et al. 1997).

Climate Change

The problem of climate change is intractable by our traditional scientific methods (Hamilton 1999). Bretherton (1994) notes that different ways in which individuals respond to uncertainty in everyday life leads to different perspectives on global environmental change that includes different views of the agenda, the analyses needed, and the scientific implications. Morgan & Dowlatabadi (1996) point out that, in addition to all the other uncertainties about climate change, we are uncertain about the identities of the decision makers. They conclude (p. 363):

> . . . the more we work on integrated assessment of climate change, the more we realize that the biggest challenges are philosophical and methodological. . . . We have never worked on a problem in which the labile and adaptive nature of values, or the number of different actors with different values, is as central as it is in climate policy. Finally, we have been doing analysis for the entire world, using basic ideas of causation, probability, and rational expectation: ideas that are probably not shared by 80% of the world's peoples. The available tools of policy analysis are simply not up to the challenges we face, so we are busy inventing new tools.

Uncertainty and Ecological Science

Complex problems such as those described in the previous section involve varying degrees of knowledge and ignorance. It is helpful to characterize the aspects that are well understood, so that they can be differentiated from those that are more problematical. There is a large literature on scientific uncertainty, but uncertainty per se in ecology has not been surveyed. Some aspects of uncertainty are considered in Levins (1966), Beck (1987), Simberloff (1988), Dovers & Handmer (1995), Hilborn et al. (1995), Lélé & Norgaard (1995), Talbot (1996), Mangel et al. (1996), and Hilborn et al. (1999). Smithson (1989) and Wynne (1992) differentiate kinds of ignorance. For example, we face risk determined by the significance level if we reject a null hypothesis. We may be uncertain about the value of a parameter that measures the strength of competition between two species with similar requirements. A few well-designed experiments may remove such uncertainty. We may be ignorant about the form of a predation response: Is it Holling type I, II, or III? Reduction of such ignorance may require a long series of well-controlled experiments. It may be undetermined whether a community is structured by competition, predation, or some other interaction. It may be impossible to give a general solution of such indeterminate problems. The answer may vary from species to species, from place to place, and from time to time. The implications of these different kinds of uncertainty are profound for both sustainability and application of a precautionary approach (Dovers & Handmer 1995). Although we may often use stochastic models, fundamental ignorance may dominate fluctuations. Harcourt (1995) notes, in work on the population viability of the Virunga gorilla (*Gorilla gorilla*): (p. 134) "Deterministic change in habitat is a greater threat than stochastic demographic variation, and yet our ecological ignorance is such that we could not begin to model the consequences of removal of even the main food plant." Similarly, in view of recent amphibian declines (Pounds et al. 1997, Alford & Richards 1992), action may be required before the full story is known. The different types of uncertainty may mandate different types of actions. The fundamental law in biology—evolution by natural selection—is not a predictive law in the sense of Newton's equations (Maddox 1999). The more detailed implications of this fundamental law, such as the rules that characterize population growth and interaction or energy flows, are typically unknown or may vary from one system to another (Shrader-Frechette & McCoy 1993). This forces ecologists to create and use a variety of models of uncertain validity (Crowder et al. 1994, Halley & Dempster 1996, Berryman 1997, Starfield 1997).

Data and Their Interpretation: Hypothesis Testing and Bayesian Inference

In spite of the lack of sweeping general laws such as those in physics, ecologists can make statistical inferences from their data. These are useful provided that the chain of inference is well documented. The most commonly used method is hypothesis testing. Although application of the technique is straightforward, there are many pitfalls in interpretation. Imagine that we are interested in an ecological hypothesis H and have collected some data D in the course of investigating the hypothesis. Ideally, we wish to know the probability that H is true, given the data D. Symbolically we write

$$\Pr\{H \mid D\} = \text{Probability that } H \text{ is true, given the data.} \qquad 1.$$

However, in using the approach of hypothesis testing, we construct a null hypothesis H_0, which is the complement of H in the sense that

$$\Pr\{H\} + \Pr\{H_0\} = 1. \quad 2.$$

We then evaluate the probability of observing the data D (or results more extreme) on the assumption that H_0 is true:

$$\Pr\{D|H_0\} = \text{Probability of observing data } D \text{ (or more extreme results) when } H_0 \text{ is true.} \quad 3.$$

The problem is this: it is rarely true that the quantities in Equations 1 and 3 are equal; in symbols

$$\Pr\{D|H_0\} \neq \Pr\{H|D\} \quad 4.$$

The quantities on either side of relationship {4} refer to incompatible ways of viewing the data and the hypotheses. For the left-hand side of {4}, the hypothesis is either true or false; there is no probability associated with its truth. The data are random, drawn from the infinite set of data possible under conditions where H_0 is true. For the right-hand side of {4}, the truth of the hypothesis is random, and we wish to calculate its probability in view of the single set of data at hand.

Relationship {4} aside, the most common error in interpretation is to draw an inference from failure to reject a null hypothesis. Failure to reject is often taken as evidence in favor of the null hypothesis; some even believe that the truth of the null hypothesis is thereby established (Brook et al. 2000). However, the significance level addresses only the issue of false rejection of the null hypothesis, assuming its truth. If the null hypothesis is not rejected, the quantity of interest is the probability of accepting the null hypothesis when it is, in fact, false. The complement of this quantity is termed the power of the test, and it depends upon which alternative to the null hypothesis is, in fact, true (Peterman 1990, Peterman & M'Gonigle 1992, Osenberg et al. 1994, Steidl et al. 1997). Management based on hypothesis testing without consideration of the power of the test may be disastrous, as we show below. A second error in interpretation of hypothesis testing is to interpret the significance level as the probability that the null hypothesis is true. As we have pointed out above, such an inference is nonsensical in standard (frequentist) statistics, because hypotheses are either true or false in that framework: They do not have probabilities attached to them.

On the other hand, Bayesian statistics assigns probabilities to hypotheses (Apostolakis 1990, Howson & Urbach 1993, Hilborn & Mangel 1997, Press 1997, Malakoff 1999, Wade 2000). A Bayesian approach proceeds as follows (Hilborn & Mangel 1997). Suppose that p is the probability that the hypothesis of interest H is true; then $1 - \mathrm{p}$ is the probability that the null hypothesis H_0 is true. If we apply the definition of conditional probability, with $\Pr\{H,D\}$ denoting the probability that H is true and of observing the data D, the result is

$$\Pr\{H|D\} = \Pr\{D|H\}\Pr\{H\}/\Pr\{D\}, \quad 5.$$

where $\Pr\{D\}$ is the probability of observing the data. Since

$$\Pr\{H,D\} = \Pr\{D|H\}\Pr\{H\} = \Pr\{D|H\}\mathrm{p}, \qquad 6.$$

and

$$\Pr\{D\} = \Pr\{D|H\}\mathrm{p} + \Pr\{D|H_0\}(1-\mathrm{p}), \qquad 7.$$

we obtain

$$\Pr\{H|D\} = \Pr\{D|H\}\mathrm{p}/[\Pr\{D|H\}\mathrm{p} + \Pr\{D|H_0\}(1-\mathrm{p})]. \qquad 8.$$

Equation 8 gives us what we want, and generalizes in a natural manner for cases in which multiple hypotheses are possible explanations.

There are various objections to Bayesian inference. Some concern technical difficulties in implementing it, and about the manner in which the value of p (called the prior probability of hypothesis *H*) is chosen. Dennis (1996) claims that Bayesian methods are not useful for ecological research. He objects (rightly in our view) to Bayesian neglect of methods such as randomization, examination of residuals, and design of sample surveys; these should also be part of the toolkit. Anderson (1998) presents psychological evidence that people find it difficult to reason about probabilities attached to hypotheses. She recommends standardization and improved methods of presentation to overcome some of these difficulties. It is fair to say that Bayesian methods avoid some common pitfalls of scientific inference and interpretation, but the limitations of Bayesian methods should also be recognized; they are best used as part of a comprehensive framework of analysis. Methods of choosing and implementing appropriate statistical methods are undergoing vigorous development; see Mayo (1996) and references therein.

Uncertainty

Uncertainty about the value of a parameter can be addressed by ordinary statistical methods. A common omission in interpretation of data is to fail to draw the full implications when the null hypothesis is rejected. An effect has been detected; is it of biological (as opposed to statistical) significance? If the data are sufficient to justify rejection of the null hypothesis, they are generally sufficient to supply a quantitative estimate of the size of the effect; one should not terminate the analysis with rejection. Confidence intervals are a common tool for such assessment, but their interpretation is problematical. A common error is to interpret a 95% confidence interval by stating that the probability that the quantity lies within the interval is 95%. This is nonsense in frequentist statistics because (as described above) hypotheses don't have probabilities. Bayesian credibility intervals do have the desired property; they are determined by finding the smallest set of hypotheses that have a given total probability. A Bayesian posterior distribution assigns probabilities to all combinations of hypotheses. Thus it conveys more information than a few credibility intervals, since all credibility intervals can be computed from it. Ironically, the calculations for the Bayesian analysis are often identical to those for a conventional analysis, but the conventional result is interpreted as Bayesian (attaching a probability to a hypothesis) even though frequentists may object vigorously to Bayesian approaches.

Ignorance About Model Structure

Although the method of multiple hypotheses (Chamberlain 1897) was clearly enunciated more than one hundred years ago, scientists still tend to use one model rather than a variety of models and tend to force problems into a format that their one model can handle (Hilborn & Mangel 1997). For some recent exceptions that deal with dispersal and invasion, see Kot et al. (1995), Rejmanek & Richardson (1996), or Clark et al. (1998); population trajectories, see Kot et al. (1995), Rejmanek & Richardson (1996), or Clark et al. (1998); trophic cascades, see Strong et al. (1999); abundance range relationships, see Gaston et al. (1997). These are all recent applications.

The over-reliance on single models has two consequences. The first is even the best ecological journals generally require that analysis of data be conducted in the context of a hypothesis test. As we indicated above, it is preferable to estimate parameters that describe how a response is related to a putative cause. A second consequence of adherence to a single model is that one may end up like Ptolemy, "who tinkered endlessly with his cosmological theory to preserve the fiction that the earth was at the center of the universe. When the heavenly lights failed to move in perfect circles around the earth, he proposed that their orbits included curlicues called epicycles. And when observation and theory still wouldn't mesh, he added epicycles to the epicycles" (Johnson 1999, p. 235). Ignorance about model structure is best addressed within the context of multiple hypotheses, with results adjudicated by the data. Bayesian methods are well suited to this purpose, but a variety of approaches based upon consideration of likelihood will also serve (Edwards 1972).

Response to Various Degrees of Uncertainty

The manner in which humans respond to uncertainty has received considerable attention in psychological literature (Wallsten 1980, Hogarth 1983), in political literature (Linnerooth 1984), and in some ecological literature (Funtowicz & Ravetz 1991; Morgan & Dowlatabati 1996; Hilborn et al. 1999; Lempert et al. 1996; Murphy & Noon 1991, 1992; Smithson 1989; Van Valen 1982). One approach is to ignore uncertainty in all of its forms. In fact, there may be times when a deterministic model suffices. Caughley (1994) notes that conservation biology was driven by two different threads—what causes populations to become small, and what happens to populations once they are small. He states: "The declining population paradigm ... is urgently in need of more theory. The small population paradigm ... needs more practice. Each has much to learn from the other. A cautious intermixing of the two might well lead to a reduction in the rate at which species are presently going extinct" (p. 215). Caughley's dichotomy was not well received by the establishment of conservation biology (Hedrick et al. 1996). Ecologists have recognized the necessity of stochastic approaches ever since the classic experiments of Park on flour beetles. Nevertheless, classic fisheries, forest, and wildlife management typically use deterministic models with known parameters, whereas the systems typically show large random fluctuations, and the model parameters are poorly determined from available data (Hilborn & Walters 1992, Quinn & Deriso 1999). Scientists may be asked to make deterministic predictions in situations that are poorly understood, or where environmental and population fluctuations are important (Shrader-Frechette 1993, Oreskes et al. 1994, Lauck et al. 1998, Taylor et al. 2000).

There is always an element of risk in adopting a course of action. Even carefully planned and well thought-out management plans may fail. The public should not be led to expect success in every ecologically based plan. The sort of risk that is analogous to flipping a coin does not present major difficulties for planning. The situation is more problematical for other types of uncertainty. Because ecological data may be expensive to collect, sparse, or of poor quality, critical parameters and processes may be poorly determined (Walters & Ludwig 1981, Ludwig & Walters 1981). There is a temptation to make recommendations on the basis of best available data in situations that are of critical importance (Ruckelshaus et al. 1997, Slade et al. 1998). This often means adopting a single best value for a parameter and a best hypothesis about the structure of the system. Such an approach may be misleading because it ignores the range of consequences that are plausible but not excluded on the basis of available data (Mangel et al. 1996).

A particularly harmful practice is to apply hypothesis testing methods to management situations. If one insists upon significant results at a 95% level before taking action, timely action may never be taken. Doak (1995) uses simple source sink models to analyze habitat degradation and grizzly bear (*Ursus arctos horribilis*) persistence. The models allowed a power analysis of habitat degradation and showed that if habitat loss is slow, more than a decade may pass between when the critical amount of habitat is lost and when it can be detected under best circumstances; also see Mangel & Hofman (1999). Johnston et al. (2000) apply power analysis to a situation where stocks of harp seal (*Pagophilus groenlandicus*) are judged not to be at risk unless a statistically significant decline is observed. They point out that a trend of 1.5% could be detected with a probability of 95% only after 19 annual surveys; detection of a trend of 0.5% would require 39 annual surveys. That is, after 10–15 years of a 1.5% decline per year, one would not be able to determine with 95% probability that the stock had declined, even though the stock decline would be considerable. Thus, the burden of proof for those who wish to assert that human intervention in an ecosystem shows lack of effect is considerably more complicated than applying a hypothesis test (Hilborn & Ludwig 1993, Mangel 1993).

How can we make decisions when there is ignorance about the model structure? One approach is to analyze the consequences of various types of error. McElroy et al. (1997) discuss the trade-off between type I and type II errors (which they call the "producer's versus consumer's risk") in the analysis of an endangered species problem. Within the context of classical statistics, an objective might be to minimize the chance of a type I error while maximizing power. Another approach might be to attempt to minimize the probability of the worst possible scenario. This last approach is not very stable, because there is no limit to possible scenarios. A better procedure would be one in which the differing scenarios are weighted by their plausibility (Lindley 1985). Decision theory (e.g., Ralls & Starfield 1994) provides a framework in which one can be pragmatic, defined by Farber (1999) as:

> Being pragmatic does not mean the rejection of rules or principles in favor of ad hoc decision making or raw intuition. Rather, it means a rejection of the view that rules, in and of themselves, dictate outcomes. ... Hard policy decisions can't be programmed into a spreadsheet. ... But we also need an analytic framework to help structure the process of making environmental decisions. Intuition is often an unhelpful guide because environmental law concerns issues outside our normal, everyday experience.... Rather than rigid rules or mechanical techniques, we need a framework that leaves us open to the unique attributes of each case, without losing track of our more general normative commitments. (pp. 10, 11).

Instead of making isolated decisions on the basis of a fixed body of knowledge, adaptive management (Walters & Hilborn 1978, Walters 1986, Williams 1996, Parma et al. 1998, Shea et al. 1998) regards each decision as part of an ongoing series; our knowledge of the system may change in response to these decisions. Adaptive management is commonly stated as a goal of management, but is widely misunderstood. Adaptive management does not consist of trial and error, i.e., adapting after something untoward happens; it requires a prior experimental design and generally long-term studies. Such long-term study may be unwarranted or difficult to justify because of economic discounting of uncertain returns in the far future (Ludwig & Hilborn 1983, Walters 1986, Halbert 1993, Taylor et al. 1997, Walters 1997). We can learn from careful comparative studies where management has been adaptive or tried to be adaptive (Gunderson et al. 1995).

Radical Uncertainty

The preceding approaches can be effective as long as the structure of the system is reasonably well understood. None of them is sufficient to make important decisions because, as we indicated above, a host of considerations (not all of which are scientific) must be examined. In some cases information about natural history may be essential, but not yet available. In such cases of overwhelming ignorance it is important not to be swayed by expert opinion that is mere guesswork, or by databases that are lacking in empirical foundations. There are many important cases in which prediction (even in the probabilistic sense) may not be possible. Structural uncertainties such as natural catastrophes or unforeseen consequences of human interventions are important, but inherently unpredictable (Simberloff 1988, Menges 1990, Schoener & Spiller 1992, Mangel & Tier 1994, Young 1994, Root 1998, Ludwig 1999).

Even when the system is more or less understood, it may be that objectives are fundamentally in conflict. Jackson (1997) discusses the situation in which one wishes to minimize PCBs in fish and maximize the chance of sustainable fisheries. These goals are in conflict because minimizing PCBs requires increased stocking rates of chinook salmon (the predator), which then may increase the probability that the prey species (alewives) will decline with an associated reduction in the chance of a sustainable fishery. As pointed out above, for the problem of climate change even the identities of the decision-makers are not known with certainty.

Science in Support of Policy Making

Although ecologists are often consulted in deciding a great variety of issues, they may feel that their results are distorted or their advice ignored. What causes this lack of trust, lack of proper weighting of scientific opinion and advice, or, stated broadly, the inability of those seeking the consultations to effectively utilize scientific input in the public policy process? The issue is complicated by misunderstanding or misstatements of the reliability of scientific inferences on both sides of the technical divide. As we have indicated above, there are many obstacles in the path to firm conclusions. Scientists are usually aware of these difficulties at some level, but they may also exaggerate the extent of their adherence to general principles of scientific inference. In their zeal to communicate clearly and forcefully—or perhaps in an attempt to achieve unique authority—they may neglect the more troublesome aspects of particular inferences. For instance, many scientists advocate the campaign for 20% of the world's oceans to be marine reserves by 2020. However, a 20% reserve will improve sustainability of the stock only if the biological characteristics of the stock and fishing pressure outside of the reserve are at appropriate levels (Mangel 2000). When pressed, proponents of 20% by 2020 acknowledge that their advocacy is based on political realities rather than a scientific analysis. Media and political figures have their own reasons to exaggerate the reliability of scientific inference, because it is often advantageous to pretend that important political and social issues can be reduced to technical ones and put in the hands of technicians. Examples are given below under the heading Equity, Values, and the Public Policy Process. The public response may vacillate between unquestioning acceptance of dicta supposedly backed by scientific fact, and wholesale rejection of the process as politically and ideologically motivated (Butler 2000, Dickson 2000).

Where scientific input to policy discussions is potentially significant, both the science and policy tend to be distorted (Bolin 1994, Lélé & Norgaard 1996). The entanglement of political and social objectives may not be apparent to the scientists involved. As a case in point, Sagoff (1985) cites the hypothesis that ecological diversity promotes stability. This is an important hypothesis that may be true in some circumstances, but it is by no means firmly established as a general principle (Grime 1997, Hooper & Vitousek 1997, Tilman et al. 1997, McCann 2000). Yet it has become entangled with calls for preservation of biodiversity that are rallying cries for those concerned about widespread destruction of habitats and other human assaults upon our life support system (Kaiser 2000); see the remarkable exchange in *The Bulletin of the Ecological Society of America* (Wardle et al. 2000, Tilman 2000, Naeem 2000). It is ironic that when stability and diversity relationships are discussed in introductory ecology, they are appropriately introduced as a scientific debate, yet when they enter the policy arena it becomes a fact that diversity promotes stability. The scientist acting as an advisor "must recognize, not necessarily accept, political or other constraints under which a decision-maker is acting" (Bolin 1994, p. 25) and be careful not to distort the science.

The Process of Policy-Making

Ecologists provide input to a complex, evolving, political process out of which policy emerges. The policy process involves the preparation, expression, and implementation of a government opinion or course of action. Policies can be expressed through: 1. goals articulated by political leaders; 2. points of view expressed by representatives of government agencies; 3. formal statutes, rules, or regulations; and 4. practices of administrative agencies and courts charged with implementing or overseeing programs. A policy process can occur anywhere in the government, even the judicial bench. Broad descriptions of this process start with an agenda-setting process, proceed through intermediate steps of policy formation, legitimation, and implementation, and then conclude with review and revision of existing policies (Kraft 1996, Hempel 1996). Ecologists may participate at all stages in the policy process. Here we focus on scientific input to regulatory decision-making.

From the policy-process perspective, one reason for disregard of scientific advice may be political influence. Regulatory decisions cannot escape such influence because of the necessity of accommodating various stakeholders. The behavior of regulatory agencies may sometimes seem to conflict with their mandate to protect the public interest. This can be understood as follows. Most public agencies depend upon steady support from the legislatures that established them. This support is best achieved if a group of constituents (typically those who are most affected by the actions of the agency) influence the legislature to support the agency. Influence may be exerted by mustering votes, or campaign contributions, or both. Such legislative support is easiest to mobilize if a small group derives substantial benefits from a sympathetic stance by the agency. These principles apply, in the United States, to such agencies as the Army Corps of Engineers, the Bureau of Land Management, the National Forest Service, and the National Park Service (Maas 1951, Clarke & McCool 1985, Culhane 1981). The Army Corps of Engineers and Bureau of Land Management are examples of successful bureaucracies because their staff and appropriations rise steadily. These agencies have well-organized supporters who benefit substantially from their activities. In contrast, the National

Park Service has had a continual struggle to obtain support. Many thousands of people enjoy services from national parks, but they are not readily organized into a lobby to protect the interests of the National Park Service. In cases where industries are regulated, the industry has a strong interest in supporting agencies that protect the interest of the industry, but much less interest in supporting an agency that looks after the public interest. This frequently results in "capture" of regulatory agencies by the industries they are supposed to regulate (McConnell 1966, Trebilcock 1978, Rourke 1984, Schrecker, 1990).

Another reason for discounting the input of ecologists to public policy concerns the form of the data and recommendations that ecologists provide. Scientists often have difficulty in communicating the implications of technical analyses of complex issues. The policy process (especially in industrialized nations) has come to expect relatively simple, precise (often interpreted as "correct") answers from scientists. If ecologists (or any scientists) fail to provide firm predictions, they may be less influential in policy discussions (Glantz 1979, Saetersdahl 1979, Saville 1979, Walters & Maguire 1996, Finlayson and McCay 1997). On the other hand, if scientists overstate the reliability of their results, they may eventually cause a lack of public trust in scientific advice (Haerlin & Parr 1999). Perhaps the most outstanding example of overstatement of reliability has been the selling of nuclear power (Shrader-Frechette 1993). Scientists may overestimate the impact of phenomena because of their concern about the organisms involved. Garshelis (1997) concludes that the previous estimates of sea otter mortality in the *Exxon Valdez* oil spill had been too high because scientists used inadequate data and then notes (pp. 913–914):

> Scientifically unsound death tolls may have even more profound implications in terms of their effect on public opinion . . . the lower estimate may seem low only by comparison . . . Once numbers are made public, however, they become a benchmark by which to judge all subsequent estimates, including those from future environmental catastrophes. Conservation hinges on public opinion, and public opinion is shaped by the information provided by scientists. If conservation biologists are to be regarded as rigorous and objective scientists . . . they must adhere to high scientific standards . . . and must admit to the limits and uncertainties in their work . . . Biologists involved in assessing the impacts of such events must keep in mind that their work will be intensely scrutinized and that their errors will affect the credibility and hence the effectiveness of conservation biologists in general.

These issues will become especially important if the Endangered Species Act is successful and species are considered for delisting (Pagel et al. 1996), because "There are no easy genetic or demographic answers to the questions of 'when is recovery complete', or 'how should fiscal triage be applied to provide the best in situ conservation of a listed species?'" (p. 434). Great care must be taken to avoid averaging different scientific positions as a mechanism for reaching consensus. Similarly, when predictions do not come true, as in the mineral resource shortages predicted in the 1950s–1980s (Hodges 1995), we must ask why this is the case.

Equity, Values, and The Public Policy Process

Because regulatory decisions typically involve conflict between opposing interests and values, an immediate issue is the relative power and resources available to various groups. For example, public interest groups rarely attend routine advisory committee meetings, but industry is generally well represented (Jasanoff 1990, p. 247). Hence significant policy decisions, particularly decisions not to act, may be reached after deliberations inordinately influenced by only one set of interests. Jasanoff (1990) attributes this difference in attendance to the differing resources available to the two groups. But if decisions are perceived as arbitrary or excessively favoring one group over another, they tend to be discredited, and they invite litigation.

Most governmental regulations impose costs on one segment of the population, and provide benefits to a different segment. Hence the evaluation of regulations involves weighing of disparate sets of values and interests. This is manifestly not a scientific exercise. Governmental officials may attempt to convert a difficult political issue into a technical problem by involving expert scientific advice. Recent advice to the British government on bovine spongiform encephalopathy (BSE) is an example (Loder 1999; Haerlin & Parr 1999). The administrative dilemma was whether to expose the whole population to a risk of infection or to destroy an industry. The administrative solution was to convert this impossible choice into a technical evaluation of the risk of infection from eating British beef (Ridley 1999). No amount of scientific evidence can prove that there is no risk, because that is beyond the capability of scientific inference. Nevertheless, the government contrived to produce such a verdict from an eminent scientific panel. The French government, acting for a different set of constituents, decided to ban British beef. The final resolution, reached in the fall of 1999, was arbitrated by a scientific panel of the European Union, but the scientific conclusions had little effect on the political process.

Hutchings et al. (1997) write, "We contend that political and bureaucratic interference in government fisheries science compromises the DFO's [Department of Fisheries and Oceans of the Government of Canada] efforts to sustain fish stocks and, thereby, the socioeconomic well-being of fishing people and fishing communities." They go on to document how the DFO suppressed and ignored evidence that declines in northern cod (*Gadus morhua*) stocks might be caused by overfishing. They also report instructions to DFO scientific staff that they must support the Minister's position on adequate stream flows for conservation of salmon stocks (*Oncorhynchus* spp.) while adhering to the scientific advice. Those who were unable to do so were advised to find other employment. See also Charles (1995), Kurlansky (1997), Taylor (1995), and Myers et al. (1997).

The role of values in formulating regulations is not always appreciated. Whittemore (1983) has shown how values enter into risk assessment for environmental toxicants. Brunk et al. (1991) describe a situation in which scientific panels employed by industry and the unions arrived at wildly disparate estimates of acceptable exposures for Alachlor, based upon the same scientific evidence. An analogous incident involved the California sardine, in which action was not taken to reduce harvests because the scientific evidence was inconclusive, is described by Radovich (1981); also see McEvoy (1986). Costanza & Folke (1997) note that managers of the Patuxent River drainage basin in Maryland are attempting to embed three sets of values—surrounding efficiency, fairness, and sustainability—in ecological-economic modeling and analysis. Haddad (2000) argues that policy analysis should be organized around the categories of feasibility and appropriateness, the latter of which is concerned with values.

Drawing Boundaries Between Science and Policy

Experience with regulatory science shows that boundaries between science and policy are difficult to draw and that they may require a long period of trial and negotiation (Salter 1988, Brunk et al. 1991). Jasanoff (1990) provides a history of several decisions made by the Environmental Protection Agency (EPA) and the Food and Drug Administration (FDA) in the United States. According to Jasonoff, the Scientific Advisory Board (SAB) of the EPA was created in 1974 in response to a requirement by the U.S. Congress that the EPA consult with external scientific advisors. The EPA's procedures had been under attack for its use of unpublished and unreviewed data. Its methods had frequently been challenged in the courts, and a National Academy of Sciences (NAS) study suggested that the adversarial process might better be replaced by one involving technical rationality. The composition of the SAB immediately became a political issue. Funding for the scientific activities of the EPA was cut, and a hit list of EPA's scientific advisors, compiled by the Reagan administration, was uncovered in 1983. Political involvement seems inevitable, because questions to be decided in regulatory science generally involve subjective judgment. Eventually an accommodation was reached involving an agreement between the EPA and the SAB on the boundaries between science and policy. This process included early decisions that were challenged because of lack of competent scientific advice, later decisions in which the composition of the scientific panel was stacked to favor one set of values over another, and still later ones in which there was substantial cooperation between the agency and scientific advisory committees. The latter process involved negotiations and compromise concerning the jurisdictions of the scientific advisory committee and the agency staff. It was impossible to make a complete separation between the science and the policy, for the reasons given above. Nevertheless, in cases where a compromise could be reached, it led to a much smoother process and greater acceptance of the final results by all parties.

How Can We Provide Sound and Influential Scientific Advice?

If we accept that decisions about environmental problems inevitably combine scientific and political aspects, how can scientific input be both sound and influential?

One means may be to broaden the composition of the panel providing advice. Natural scientists are accustomed to thinking of themselves as objective, but they are influenced by cultural and social differences between one group and another. For example, scientists involved in fishery management are sometimes charged with a tendency to discount traditional knowledge and anecdotal evidence in favor of the more structured forms of information available from industrial sources (Finlayson & McCay 1997, Berkes & Folke 1998). Funtowicz et al. (1999) point out that systems of management of environmental problems that do not involve science, and which cannot immediately be explained on scientific principles, are commonly dismissed as the products of blind tradition or chance. When people with no formal qualifications attempt to participate in the processes of innovation, evaluation, or decision, their efforts may be viewed with scorn or suspicion. Such attitudes do not arise from malevolence; they are inevitable products of scientific training, which presupposes and then indoctrinates, the assumption that all problems are amenable to scientific methods.

These observations suggest that scientific panels would benefit from more diverse composition and input. In contrast to natural scientists, sociologists and anthropologists who study resource systems tend to emphasize the value of multiple forms, methods, and means of acquiring and validating knowledge. This difference in outlook between natural and social scientists may help to balance what otherwise might be a very lopsided set of deliberations (Finlayson & McCay 1997; Berkes & Folke 1998). There are risks as well as benefits associated with broadening advisory panels, because results of natural science may not be understood or trusted by all the participants. In order to mitigate such effects, it may be well to change the format in which advice is presented. Ozawa (1991) describes how consensus-based methods may help to lessen the gap between expert and the laity, and improve the quality of expert advice. Consensus-based methods are aimed at obtaining approval from all participants. A preliminary series of meetings is held to discuss proposed regulation. A special master convenes discussions on scientific bases for the decision. Scientists participate in intensive question-and-answer sessions, and present alternative interpretations or alternative analysis. The objective of consensus-based methods is to bring all individuals up to a common plane of technical competency. When experts are aware that they must explain the logic of their arguments rather than simply ride on their reputations to win concurrence, they make more serious efforts to educate the stakeholders. The division between experts and nonexperts narrows, and science benefits by having a more knowledgeable public. A similar process is envisaged by Clark et al. (2000). The result of a consensus-based approach may be very different from a method in which uncertainties are neglected by concocting a single best estimate of the state of the system. A common understanding of the scientific issues and uncertainties enables a variety of stakeholders to support their interests effectively. The politics of environmental mediation (a quite different process) is dealt with in Amy (1983, 1987) and Weber (1998).

THE NEXT GENERATION OF ECOLOGISTS

It is clear from the preceding discussion that ecologists face unprecedented challenges and opportunities when dealing with environmental issues. How can we prepare ourselves to deal with these issues? As we pointed out in the Introduction, traditional disciplines and training are inadequate for wicked problems involving the interaction of humans with their environment. This has crucial implications for the future training of ecologists. The important problems that we face can be dealt with only by combining insights from a variety of sources. There is much to be learned from history, religion, philosophy, geography, economics, political science, and other disciplines. The training for those interested in solving environmental problems must be broader and deeper than the training of a disciplinary scholar. To be successful, interdisciplinary training must be more—not less—rigorous than disciplinary training. That is, interdisciplinary training requires mastering the core skills, not just the key words, in disciplines of the natural and social sciences.

Disciplines are Essential, but Disciplinary Boundaries are an Impediment

Great progress has been made by defining the natural scientific disciplines and by setting up disciplinary boundaries. Science progressed as it shed metaphysical and religious dogma from its scope. Following Francis Bacon, scientists have attempted to exclude internal bias from our interpretation of empirical observation (Roszak 1972, Gould 2000). Biology progressed by rejecting vitalism (Mayr 1982). Ecology progressed by excluding human interventions from its scope: we generally consider that an experiment has been hopelessly compromised if there are unplanned applications of pesticides or other disruptions of the study site.

This progress has imposed costs. Attached to the dogma and biases was context: an implicit recognition that what scientists of one era considered rational in terms of methods and proof might be different from the beliefs of earlier or later scientists (Toulmin 1990). The Austrian economist von Hayek (1945) extolled the importance of "the knowledge of particular circumstances of time and place" in operating economic systems. Declining respect for context in science reduces the value scientists place on knowledge of long-standing, effective institutional regimes for managing ecosystems. Many perceive a conflict between science and religion, but Benjamin & Mangel (1999) note a connection between parts of the Hebrew Bible and modern statistical thinking; they note that much of the challenge raised by Darwin was to social structure rather than to deep religious thinking.

Our relationship with nature has suffered from the Newtonian concept of biological organisms (including humans) as machines (Callicott 1994, Callicott 1999, Hodgson 1999) rather than as complex adaptive systems (Waldrop 1992, Lewin 2000) and has led to oxymorons such as "ecosystem management" or "maximum sustainable yield" (Grumbine 1994, Wood 1994, Ludwig 1994, Stanley 1995). The artificial distinction between natural and social sciences has produced many anomalies. Ecologists produced a manifestly political "Sustainable Biosphere Initiative" (Lubchenko et al. 1991) that ignores human population dynamics and patterns of resource use (Grumbine 1994, Wood 1994, Ludwig 1994, Stanley 1995). It is futile to attempt to conserve species through protected areas if conditions leading to human encroachments are ignored. Forests cannot be conserved without consideration of their inhabitants. Problems resulting from climate change cannot be addressed without appealing to conceptions of social justice. Wicked problems cannot be addressed within the old disciplinary boundaries.

Insights from Geography, History, and Anthropology

Although we are still struggling to understand interactions between humans and their environment, there is already a rich literature. Geographers have long been concerned with human impacts and their consequences. Marsh's work of 1864 is a classic (Marsh 1965), and it has inspired more recent updates (Thomas 1956, Turner et al. 1990, Dasmann 1984). It is clear that many regional conservation problems require a geographic perspective, as Brawn and Robinson (1996 p. 10) note:

> In fragmented landscape, a regional approach to conserving migrant species appears warranted. Conservation strategies designed to reduce nest predation and parasitism in Illinois' forest birds may be ineffective without plans to maintain potential source populations within extensive forests in surrounding states . . . Lack of data on dispersal is the major gap in understanding the population dynamics of neotropical migrants and prescribing effective conservation measures.

Historians provide additional scope to the vision of man's relation to nature (Crosby 1986, Worster 1993, Cronon 1996, Diamond 1997, McNeill 2000). Worster (1993, p. 24) advises that scientists acknowledge the connection between the nature they study and thousands or millions of years of human history, its ideas and social forces:

> Environmental historians would argue that scientists need them to answer a very big question that the latter have themselves raised but are unequipped to answer: Why are we in a state of crisis with the global environment? . . . natural science cannot by itself fathom the sources of the crisis it has identified, for the sources lie not in the nature that scientists study but in the *human nature* and, especially, in the *human culture* that historians and other humanists have made their study. We are facing a global crisis today not because of how ecosystems function, but rather because of how our ethical systems function.

Redman (1999) points out that many environmental problems that we perceive today are similar to those faced by ancient societies. He suggests that the collapse of many such societies can be attributed to destruction of natural resources, perhaps prompted by institutions that promote ever higher production in order to satisfy the demands of an elite. He makes a persuasive case for the contribution of archaeology to the discussion of environmental problems. Bodley (1990) claims that environmental problems must be viewed in long-term perspective as a struggle between two incompatible cultural systems—tribes and states. The most critical features of tribal groups are their political independence, reliance on local natural resources, and relative internal social equality. In comparison with states, and especially industrial states, tribal systems tend to expand more slowly and have been environmentally less destructive. These differences explain why territories still controlled by tribal groups are so attractive to developing nations because tribal territories contain "underutilized" resources. Bodley goes on to explain how the ensuing pattern of exploitation is justified by an ethnocentric attitude that nullifies the interests and rights of indigenous people (WCFSD 1999, Clad 1988, Goodland 1988, Wells et al. 1999, Wells & Brandon 1992, Brandon 1997, van Schaik et al. 1997, Sanderson & Redford 1997). There is an interesting debate in an issue of *Conservation Biology* about the relationship between indigenous peoples and conservation. Redford & Stearman (1993a, p. 252) point out the great diversity of indigenous groups, and the severe pressures that have left many of them destitute and estranged from traditional ways. They state "To expect indigenous people to retain traditional low-impact patterns of resource use is to deny them the right to grow and change in ways compatible with the rest of humanity." The discussion continues with Alcorn (1993), and Redford & Stearman (1993b). Also see Ruttan & Borgerhoff-Mulder (1999) and more recent issues of *Conservation Biology*. Ponting (1992) provides many examples of tribal groups causing severe environmental problems.

If we adopt a more sympathetic attitude towards traditional peoples and their ways, perhaps we can learn something of value for our present problems. Ostrom (1990) provides a well-articulated account of things to be learned. Ostrom is concerned with "Common Pool Resources" such as fisheries, in which there is joint management of the stock but the proceeds of the harvest accrue to individuals. She lists properties that tend to promote successful management, such as clearly defined rights and norms of behavior, collective choice in devising and application of such rules, monitoring of compliance by the participants, graduated sanctions for offenses, a mechanism for conflict resolution, and protection of local rights to organize from challenges by external authorities. She (Ostrom 1992) gives a series of injunctions for those contemplating modification of local institutions. In essence, these involve knowledge of and respect for existing rules and institutions. Perhaps most important, she advises that one should propose new rules only if there are no existing rules, or if existing rules are ineffective, and if one is thoroughly familiar with the configuration of existing institutions and their function. Also see Berkes (1999), Berkes & Folke (1998), Gadgil et al. (1993), Gadgil & Malhotra (1994), Hanna et al. (1996), and Ostrom et al. (1999).

Insights from Economics

The relationship between economics and ecology has been a vexing one. Both fields of study share the Greek root oikos, which means "home," and both address questions of scarcity and competition. By the early twentieth century, mainstream economics had adopted a mechanistic perspective closely linked to Newtonian mechanics (Hodgson 1999) and elaborated an economic interpretation of utilitarian ethics. Both of these century-long themes have had profound implications for relations between economics and ecology. Arguments in favor of economically-efficient resource use have played roles in the passage of major U.S. environmental legislation (Cropper & Oates 1992). Gillis (1991) uses economics to critique policies with direct and indirect environmental impacts. He cites artificially low grazing fees that led to overgrazing and desertification, near zero prices charged for irrigation water, and maldistribution of income as major causes of ecological problems. The development of nonmarket valuation techniques, including contingent valuation, has enabled policy-makers to consider the value of forests and wetlands on other terms than simply sources of raw-material inputs to the economy (NOAA 1993, Hanemann 1994). Within the mainstream, economic inquiry into environmental questions is known as environmental economics.

The century-old commitment of economics to mechanics and utilitarianism has imposed costs. Economists' regular use of linear dynamics, quadratic costs, and Gaussian random variables stands in contrast to ecological situations that are often unique, nonlinear, and nonGaussian. Common economic modeling assumptions such as complete reversibility of transactions and complete substitutability of goods and services are incompatible with ecologists' conceptions of evolution and uniqueness of ecosystems. The doctrinal domination of utilitarianism mutes the discussion of environmental policies that could emerge from alternative ethical bases, such as sustainability or equity (Haddad & Howarth 2001). Ecologists place much greater emphasis on experiment (as opposed to theory) than do economists. McCloskey (1994), writing for fellow economists, points out that part of professional training is inclusion of certain aspects of experience, and exclusion of others, which results in "learned incapacity." McCloskey claims that neoclassical economists' disregard for history, philosophy, geography, psychology, anthropology, sociology, law, and political science leads others to write economics off. Heilbroner (1999) also challenges the narrowness of focus of neoclassical economics. Similar criticisms can be leveled at ecology and ecologists when we attempt to advise on important policy issues but ignore other viewpoints that may be pertinent (e.g., Bodmer et al. 1994).

Growing numbers of economists are challenging mechanistic metaphors and strict adherence to utilitarianism. Evolutionary economists are attempting to restore biological metaphors and insights when explaining economic systems (Nelson & Winter 1992, Nelson 1995, Hodgson 1999, England 1994). Ecological economists are attempting to employ both evolutionary and coevolutionary perspectives (Norgaard 1984, Norgaard 1994, Gowdy 1994, Hodgson 1999) as well as to explore practical and theoretical implications of the sustainability ethic [Constanza

1991, Daly (1991, 1996), Howarth 1995, Howarth & Norgaard 1990]. A seminal work that places the human economy squarely within the confines of physical and ecological systems is Georgescu-Roegen (1971).

Amartya Sen is an exceptional economist who has been concerned with distributional issues as well as the usual criterion of economic efficiency. Sen (1999, p. 6) notes that ... no famine has ever taken place in the history of the world in a functioning democracy, be it economically rich (as in contemporary Western Europe or North America) or relatively poor (as in post-independence India, or Botswana, or Zimbabwe). Famines have tended to occur in colonial territories governed by rulers from elsewhere (as in British India or in an Ireland administered by alienated English rulers), or in one party states (as in the Ukraine in the 1930s, or China during 1958–1961, or Cambodia in the 1970s), or in military dictatorships (as in Ethiopia, or Somalia, or some of the Sahel countries in the recent past).

This is elaborated later in the work Sen (1999, pp. 160–188). Some philosophical aspects of ecological economics are discussed in Goulder & Kennedy (1997). Thoughtful introductions are given by Common (1995) and Cooper (1981). Funtowicz et al. (1999) propose multicriteria evaluation as a tool to deal with incommensurability and complexity, and they describe a variety of promising approaches. The case for an institutional economic approach (which would involve insights from a variety of social sciences) is made by Jacobs (1994). Haddad (1997, 2000) combines perspectives from institutional and ecological economics in evaluating the role of markets in environmental protection. Farber (1999) is guided by legal precedents and the history of legislative enactments of environmental protection rather than abstract arguments in favor of protection. He includes a critical discussion of cost-benefit calculations and discounting of future costs and benefits.

Insights from Political Science

Greenbaum et al. (1995) provide an excellent selection of papers dealing with environmental law and ethics. Issues of the environment and social justice are treated in Faber (1998), Sachs (1993), Westra & Wenz (1995), Low & Gleeson (1998), Mason (1999), and Coward et al. (2000). Some political scientists have been concerned with the challenges that environmental issues pose to our systems of governance. Ophuls (1977), Ophuls & Boyan (1992), and Heilbroner (1974) are pessimistic about the prospects for democratic resolution of ecological conflicts, but more recent thought has concluded that democratic institutions offer the best prospects (Paehlke 1996, Paehlke & Torgerson 1990a, John 1994, Lafferty & Meadowcroft 1996, Dryzek 1999, Faber 1998). Cortner & Moote (1999) provide a comprehensive survey of political aspects of resource management, with emphasis on newer approaches that emphasize citizen participation.

On the international level, Homer-Dixon (1991, 1994) and Homer-Dixon et al. (1993) have alerted us to possible violent conflict over resources. Some of the troubles in the Middle East are driven by a combination of conflict over oil and conflict over water (Hubbard 1991, Odell 1986, Yergin 1991, Clark 1993, Gleick 1993, Ohlsson 1995, Postel 1992, Postel 1996).

Paehlke (1989) sees environmentalism as "a political movement that seeks to impose upon the physical sciences and engineering restraints based upon the findings and judgments of the social and life sciences." Therefore, "science can never again be an activity solely devoted to removing humanity from nature, lifting us out of natural limits—for centuries, if not millennia, its implicit goal." Hence there may be a gulf between environmentalism and liberalism, and indeed between environmentalism and all ordinary, moderate politics (Berlin 1990, Ignatieff 1998). This poses a challenge for all who are concerned about the future of the earth.

Insights from Religion, Philosophy, Psychology, and Ethics

Surveys of the relationship between religion and ecology are provided in Rockefeller & Elder (1992), Callicott (1994), Anderson (1996), Berkes (1999) and Waskow (2000). From the Confucian period in China, we have sayings such as "Mountains empty, rivers gorged." Referring to cattle and goats, Meng Tse said, "To these things is owing the bare and stripped appearance of the mountain, and when people now see it, they think it was never finely wooded. But is this the nature of the mountain?" (Glacken 1956, p. 70). According to Plato, "Long ago there were abundant forests in the mountains, which provided fodder for the animals and storage for water, which could then issue forth in springs and rivers. The water was not lost, as it is today, by running off a bare ground into the sea" (Glacken 1956, p. 70). The book of *Exodus* of the Hebrew Bible contains an injunction to leave land fallow one year in seven (Dunham & Coward 2000, Waskow 1995). Religious restraints and taboos have served to protect many of the world's forests until recently. The most profound change wrought by Western influence in India was the onslaught on the Hindu concept of the forest as sacred, which had in effect made the forest an ecological reserve (Ashton 1988, Gadgil & Guha 1992, Gadgil et al. 1997). Shalomi (1993) has called for the development of a "Gaia theology."

The classic statement of the ethical consequences of an ecological and evolutionary perspective is Leopold (1966 [1949]). Further literature and interpretation is in Callicott (1999). The contributions in Coward et al. (2000) center around the concept of "ecosystem justice." These ideas have an ancient history. Callicott (1999) gives an interesting exposition of the various versions of creation in the book of *Genesis*. The passage about God creating man in God's own image, and giving him dominion over the earth appears first in the standard version of the text. White (1967) claims that this passage provided the ethical sanction for unrestricted exploitation of the earth and all that live in it. This interpretation, rooted in nineteenth-century Protestant thinking, did great damage to the relationship between deep religious thinking and the environment. But it is problematical, in view of the complexities of interpretation of the Hebrew Bible, written without vowels or punctuation (Herczeg 1995). The second account of the creation in *Genesis* is actually older than the first one. It refers to Adam being "formed of the dust of the ground." This image is reinforced in the name "Adam," which is derived from the Hebrew word for earth; "Eve" is connected to the Hebrew root for "life." In an interesting parallel, Weaver (1996, p. 12) quotes Salvador Palomino as follows: "The Earth, our Mother Earth, has always been part of our collectivity. We belong to her, she does not belong to us. Land and community are the souls of our peoples." A similar sentiment is expressed by Leakey (1996 p. 253), based upon the common origins of all life forms on Earth.

Roszak (1992 pp. 68, 78) explores connections between ecology and psychology, noting that "the species that destroys its own habitat in pursuit of false values, in willful ignorance of what it does, is 'mad' if the word means anything." To the extent the natural realm possesses a sacramental quality, traditional psychotherapy should insist that people remain vitally connected to nature.

Science and Values

As indicated above, scientific inferences and theories cannot be separated from the values of those who conduct research. This must be clearly understood if ecologists are to be effective in formulating and executing policies (Lélé & Norgaard 1996, Matthews 1995, Fischer 1990, Meffe & Viederman 1995, Orians et al. 1986, Soulé 1986). The relationship between science and values has been generally glossed over in training (Norton 1998) but is now generally recognized. The implications of the values of scientists can be understood through examination of case histories. See Maguire (1994) for an account of the "Wildlands Project." The connection between the mission of the management agency and scientific conclusions is particularly clear in Radovich (1981), in which scientists employed by different agencies came to differing conclusions from the same data. Also see Brunk et al. (1991) for the issue of setting standards for exposure of workers to hazardous materials. A poignant case in which scientific advice was tempered by political concerns with disastrous results for a fishery is described by Saville (1979); also see Hutchings et al. 1997.

Once we admit that environmental problems may reflect our own culture and attitudes as much as a scientific or technical problem, we have greater scope for possible responses. There is a rich literature on this topic. Caldwell (1990) identifies some dominant modern ideologies: Economism means placing an exceptional and inordinate emphasis upon utilitarian economic values in contradistinction to all others. This approach gives little or no value to nature apart from its immediate utility for economic purposes. Scientism is the belief that science, in its several meanings, is inherently capable of solving almost all human problems. It is an extrapolation from the unquestioned achievements of science, and reflects an oversimplification of the ways in which science relates to the social and political issues of human society. Technocratism is an effort to achieve policy solutions by recourse to technological innovation or through what is sometimes called a technological fix (Ehrenfeld 1978, 1993). Cotgrove (1982) points out that technocracy seeks to depoliticize value clashes by reducing them to an economic or technical calculus, as the British government did for the BSE crisis, and as all governments have done for nuclear power. The technocratic mode dismisses values that are not easily quantified or monetarized; see also Callicott (1994). The philosophical underpinnings of the contemporary approach to resource management are explained by Cortner & Moote (1999). They point out that many of our attitudes date from the period of the Enlightenment: ideals of rationality, social equality, and progress. Along with these goes an attitude of domination and mastery over nature, which is still the dominant approach to natural resources.

Perhaps the most approachable account of postmodern ideas is Norgaard (1994), who points out that although a few have attained material abundance, resource depletion and environmental degradation now endanger many and threaten the hopes of all. Modern values, knowledge, organization, and technological systems reflect the availability of fossil hydrocarbons rather than the features needed to interact, and continue to coevolve effectively, with ecosystems. Norgaard (1994) describes some consequences of an evolutionary approach. Because prediction is very difficult or impossible, experimentation should be done cautiously. Experiments that can be undone quickly are preferred. Diversity is necessary for evolution; hence it is inherently good. Most changes are likely to be selected out, but small, compatible changes can eventually change the coevolutionary course.

The idea that our attitudes toward natural systems are a social construction is part of a wide-ranging inquiry in the social sciences that has caused much conflict among natural scientists (Gould 2000, Hacking 1999). We have given some references in the context of fisheries management. Charles (1994) and Matthews (1985) have inquired into attitudes behind the recent collapse of the Northern Cod. There are three competing metaphors: biological/ecological, economic, and socio-cultural. The socio-cultural fishery has four aspects: 1. it preserves a way of life, 2. it is the employer of last resort, 3. it provides economic benefits that enable more people to survive in a mixed economy, and 4. it supports a community. During the 1970s, Canadian fishery officials moved from a biologically-driven understanding of the fishery to one that considered it governed by an open-access property regime, a perspective heavily influenced by the economic model. The social view of the fishery was championed by the Province of Newfoundland, which for many years has been faced with economic decline and emigration of its young citizens. In the end, there was no way of satisfying all of these competing interests. In fact, none was satisfied.

On the other hand, because ecologists may differ in the ways that they describe mortality, reproduction, or competition does not mean these are social constructions. They are real and we need words to describe the reality. Isaiah Berlin (1990 p. 42), writing about Comte, notes that.

> He understood the role of natural science and the true reasons for its prestige better than most contemporary thinkers. He saw no depth in mere darkness; he demanded evidence; he exposed shams; he denounced intellectual impressionism ... he provided weapons in the war against the enemies of reason, many of which are far from obsolete today. Above all he grasped the central issue of all philosophy—the distinction between words (or thoughts) that are about

words, and words (or thoughts) that are about things, and thereby helped to lay the foundation of what is best and most illuminating in modern empiricism.

In the context of our main discussion, words about words (e.g., Keller & Lloyd 1992) may contribute little to the solution of wicked problems. Indeed, not all aspects of the social sciences (any more than all aspects of the natural sciences) will be helpful in finding solutions, and we need to think carefully about which aspects of the social sciences can contribute (or at least not make things worse).

CONCLUDING REMARKS

We began this review by pointing out changes in concerns and attitude of ecologists in response to environmental problems. It is apparent at the end of this review that the challenges are broad and deep. They apply not only to ecology, but to a host of other disciplines and ways of thought, some of which might first appear to be esoteric and unrelated to major human concerns. Environmental problems challenge our concepts of experts and of rational optimizing approaches, because there frequently is no consensus on a final goal or set of objectives. As with global climate change, there may be no clearly defined set of decision-makers. Environmental problems challenge policy-makers to deal effectively with scientific data that are accurate but not precise.

Because of the great demand for reliable knowledge and prediction in the face of a host of unknowns and unknowable aspects of conservation, great demands are made on our methods of data analysis and statistical inference. Philosophical differences such as those that divide frequentists and Bayesians become pressing issues, because important decisions may hinge on the choice of adequate and reliable statistical procedures and communication of their implications. Blunders in statistical inference may have only minor consequences for research programs in well-established fields, but the potential for damage is enormous when such blunders influence environmental decisions.

Experience has shown that when science is used to support policy-making, both the science and the policy are altered in fundamental ways. The idea that science can be completely objective and value-free cannot be supported in such a context. The closer the issue is to fundamental human goals and aspirations, the more difficult it is to separate scientific conclusions from other influence. Scientists cannot expect to be granted a privileged position in environmental deliberations; they will have to devise ways of communicating their insights to a variety of people, some of whom may have quite different values and ways of knowing, and opposing interests.

Our work also has implications for policy. The coevolutionary relationship between the practices of science and policy-making suggests that the policy process also needs change. We encourage policy-makers, some of whom are themselves ecologists, to find new ways to integrate ecological knowledge into the policy process. This includes not only integrating different forms of data and conclusions based on data into decision processes, but also integrating multiple and complex expressions of values. Wicked environmental problems require not only innovative policy responses but also innovative methods of arriving at responses.

The disciplinary structure that has served science so well over past generations is inadequate to address contemporary problems. This realization is quite general over many academic disciplines. One of the most striking things we have noticed in examining material from the humanities and social sciences is the widespread feeling that, although the respective discipline has much to offer to understand and cope with environmental challenges, it will require a fundamental realignment to achieve those goals. This applies to history, geography, anthropology, economics, political science, and ethics. The science wars that emerged from social deconstruction of natural science (Hacking 1999) must be resolved in ways that facilitate exchange of insights across the disciplinary divide. The issues are no longer esoteric because we cannot progress in other ways until we progress in this one.

This is an exciting time in which to work because the challenges are new and fundamental and the opportunities are correspondingly great. We may imagine that a great bell has tolled. It makes not a single sound but a great wash of sounds, both high and low, some of them discordant and harsh. It resonates in every object within its reach. It tolls for all of us.

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