Ecological Applications, 3(4), 1993, pp. 579–581

DEVELOPING ECOLOGICAL RESEARCH THAT IS RELEVANT FOR ACHIEVING SUSTAINABILITY[1,2]

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In their excellent recent article, Ludwig et al. (1993) accurately identify many of the underlying reasons for nonsustainable resource use. They conclude by enumerating five basic principles of effective management: (1) include human motivation; (2) act before scientific consensus is reached; (3) rely on scientists to recognize problems but not to remedy them; (4) distrust claims of sustainability; and (5) confront uncertainty. I agree, in general and wholeheartedly, with all of these principles. My only quibble is with their assertion, included as an expansion of principle 4, that basic ecological research on the topics identified in the Sustainable Biosphere Initiative (SBI, Lubchenco et al. 1991) is irrelevant to achieving sustainability. A unique feature of the SBI document was that in identifying the research needs for a sustainable biosphere, a group of ecologists pinpointed many areas of research that go well beyond the boundaries of traditional ecology and require a broad, interdisciplinary collaboration. Narrow, traditional ecological research is not relevant by itself, but the broad interdisciplinary research recommended in the SBI can be. But in order for the recommended SBI research to actually be relevant, some additional major changes in how we view science in general, and especially the linkages between science and environmental policy, are going to be needed.

As Ludwig et al. (1993) point out, one of the primary reasons for the problems with current methods of environmental management is the issue of scientific uncertainty, not just its existence, but the radically different expectations and modes of operation that science and policy/management have developed to deal with it. If we are to solve this problem, we must understand and expose these differences and design better methods to incorporate uncertainty into the policy making and management process.

To understand the scope of the problem, it is necessary to differentiate between *risk* (which is an event with a *known* probability, sometimes referred to as statistical uncertainty) and *true uncertainty* (which is an event with an *unknown* probability, sometimes referred to as indeterminacy). Most important environmental problems suffer from true uncertainty, not merely risk.

Science treats uncertainty as a given, a characteristic of all information that must be honestly acknowledged and communicated. Over the years scientists have developed increasingly sophisticated methods to measure and communicate the uncertainty arising from various causes. It is important to note that the progress of science has, in general, uncovered *more* uncertainty rather than leading to the absolute precision that the lay public and some policy makers often mistakenly associate with "scientific" results.

The scientific method can only set boundaries on the limits of our knowledge. It can define the edges of the envelope of what is known, but often this envelope is very large and the shape of its interior can be a complete mystery. Science can tell us the range of uncertainty about global warming, the potential impacts of toxic chemicals, or the possible range of fish population dynamics, and maybe something about the relative probabilities of different outcomes, but in most important cases it cannot tell us which of the possible outcomes will occur with any degree of accuracy.

Our current approaches to environmental management and policy making, on the other hand, abhor uncertainty and gravitate to the edges of the scientific envelope. The reasons for this are clear. The goal of policy is making unambiguous, defensible decisions, often codified in the form of laws and regulations. While legislative language is often open to interpretation, regulations are much easier to write and enforce if they are stated in clear, black and white, absolutely certain terms.

As they are currently set up, most environmental regulations, particularly in the United States, *demand certainty* and when scientists are pressured to supply this nonexistent commodity there is not only frustration and poor communication, but mixed messages in the media as well. Because of uncertainty, environmental issues can often be manipulated by political and economic interest groups. Uncertainty about global warming is perhaps the most visible current example of this effect. In order to rationally use science to make policy we need to deal with the whole envelope of possible futures and all their implications, and not delude ourselves that certainty is possible.

The "precautionary principle" is one way the environmental regulatory community has begun to deal with the problem of true uncertainty. The principle states that rather than await certainty, regulators should

[1] Manuscript received 2 June 1993.
[2] For reprints of this Forum, see footnote 1, p. 545.

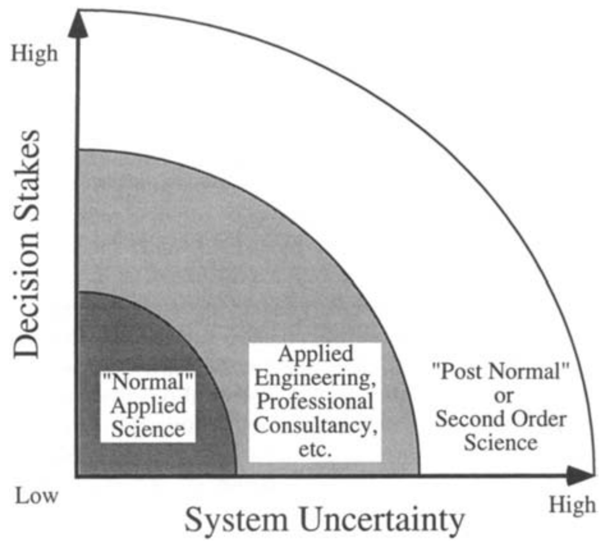

FIG. 1. Three kinds of science (from Funtowicz and Ravetz 1991).

act in anticipation of any potential environmental harm in order to prevent it. The precautionary principle is so frequently invoked in international environmental resolutions that it has come to be seen by some as a basic normative principle of international environmental law (Cameron and Abouchar 1991). But the principle offers no guidance as to what precautionary measures should be taken. It "implies the commitment of resources now to safeguard against the potentially adverse future outcomes of some decision" (Perrings 1991), but does not tell us how much resources or which adverse future outcomes are most important.

This aspect of the "size of the stakes" is a primary determinant of how uncertainty is dealt with in the political arena. The situation can be summarized as shown in Fig. 1, with uncertainty plotted against decision stakes. It is only the area near the origin with low uncertainty and low stakes that is the domain of "normal applied science." Higher uncertainty or higher stakes result in a much more politicized environment. Moderate values of either correspond to "applied engineering" or "professional consultancy" which allows a good measure of judgment and opinion to deal with risk. On the other hand, current methods are not in place to deal with high values of either stakes or uncertainty, which require a new approach, what might be called "post-normal" or "second order science" (Funtowicz and Ravetz 1991). This "new" science is really just the application of the essence of the scientific method to new territory. The scientific method does not, in its basic form, imply anything about the precision of the results achieved. It does imply a forum of open and free inquiry without preconceived answers or agendas aimed at determining the envelope of our knowledge and the magnitude of our ignorance.

Implementing this view of science requires a new approach to environmental protection that acknowledges the existence of true uncertainty rather than ignoring it, and includes mechanisms to safeguard against its potentially harmful effects, while at the same time encouraging development of lower impact technologies and the reduction of uncertainty about impacts. The precautionary principle sets the stage for this approach, but the real challenge is to develop scientific methods to determine the potential costs of uncertainty, and to adjust local incentives so that the appropriate parties pay this cost of uncertainty and have appropriate incentives to reduce its detrimental effects. Without this adjustment, the full costs of environmental damage will continue to be left out of the accounting, and the hidden subsidies from society to those who profit from environmental degradation will continue to provide strong incentives to degrade the environment beyond sustainable levels.

Ecological research (and scientific research in general) in this context, should be focused on defining the edges of the knowledge envelope. This "edge-focused" research should lead to a much more effective use of science as a way to anticipate and head off problems and to link with the policy process.

For example, had this "policy-linked, edge-focused" research been the norm, we could have easily anticipated the greenhouse effect and taken steps to minimize its potential impacts. Arhaneus first described the effect and humans' potential impact on it almost 100 yr ago (Arhaneus 1896), but it remained a scientific curiosity until the 1980s when enough data and models had been assembled to demonstrate that the effect was, in fact, likely to cause global warming. There is still much uncertainty about the magnitude of the warming and especially about its ultimate impacts, but science can do a very good job of anticipating potential problems if we focus the effort on that function, rather than on demonstrating impacts that have already occurred or trying to predict exactly what will happen. To be relevant, ecological research should therefore focus on the edges, as well as the range of uncertainty about these impacts. It should develop better methods to communicate uncertainty and reduce its detrimental impacts, and to link more effectively with other disciplines and the policy process.

How can it do this? Ludwig et al.'s (1993) principles are a good guide. We need to:

1) Include human motivation by developing linkages with the social sciences, particularly economics, to develop a comprehensive transdisciplinary synthesis. One effort in this direction has come to be called "ecological economics" (Costanza 1991).

2) Act before scientific consensus is reached by focusing on the edges of our knowledge and employing the precautionary principle to guide action (Perrings 1991).

3) Rely on ecologists and other scientists to recog-

nize the edges and worst cases, but do not rely on them to remedy the problems themselves. Research needs to be "policy-linked" and "edge-focused."

4) Distrust claims of sustainability and confront uncertainty by shifting the burden of proof from the public to the parties that stand to gain from resources use. One mechanism for doing this is through the use of "environmental assurance bonds" that require resource users to post a bond large enough to cover the worst case damages with the potential for refund if the damages are less (Costanza and Cornwell 1992).

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Ecological Applications, 3(4), 1993, pp. 581–583

ACHIEVING SUSTAINABLE DEVELOPMENT THAT IS MINDFUL OF HUMAN IMPERFECTION[1,2]

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"Uncertainty, resource exploitation, and conservation: lessons from history," by Donald Ludwig, Ray Hilborn, and Carl Walters (1993) is a cry from three people who are convinced that "sustainable development" is an "illusion," and that scientists, especially ecologists, are the principal perpetrators of this illusion. To probe the authors' discomfort more deeply, let us distinguish two kinds of illusions. Might sustainable development be an illusion, call it Type S, rooted in scientific understanding? A perpetual motion machine is a Type S illusion. Or might it be an illusion rooted in human nature, call it Type H? Modern Soviet Man, sacrificing personal welfare for the general good, turned out to be an illusion of Type H.

At the level of fisheries management, the authors implicitly argue that "sustained yield" (a necessary component of sustainable development) is also an illusion. Sustained yield would be an illusion of Type S, if substantial fishing inevitably drives the corresponding fishery to extinction. I infer that the authors believe that sustained yield is an illusion not of Type S but rather of Type H, which would be the case if every human institution invented to manage fishing were to drive the corresponding fishery to extinction. To prove the authors wrong, that is, to find that sustained yield is not an illusion at all but an attainable achievement, one would have to confirm that the population dynamics of fish are robust and that institutions for the management of fishing can be designed to operate indefinitely within that robustness.

As an outsider, I am surprised by the negative view of the role of ecological science in achieving sustainable outcomes: surely the progress in restricting whaling and poaching has been abetted by population biology.

The distinction between Type S and Type H illusions is crucially important when the argument is generalized to global sustainable development. For the sake of discussion, let us agree that what is to be evaluated are patterns of global economic activity on this planet for at least the next few hundred years. Let us further agree that for a pattern to be judged consistent with sustainable development it must meet two constraints: (1) within a small fraction of the total time under consideration (say, 50 yr out of 500 yr) nearly all of the earth's human beings achieve a lifestyle of considerable vigor and quality, and (2) during the time under consideration the survival of the human population and the populations of nearly all other species sharing this planet is not put in jeopardy as a result of life-threatening changes in the natural environment. If sustainable development so defined is an illusion of Type S, then, in

[1] Manuscript received 7 June 1993.

[2] For reprints of this Forum, see footnote 1, p. 545.