decisions but are not necessarily the best of decision makers.

SBI calls for immense intellectual effort for achieving self-imposed goals. Just as the overall goal rests on empirical assumptions about sustainability, each of the subsidiary goals hinges on at least one undemonstrated empirical assumption. For example "Greater attention should be devoted to examine the ways that ecological complexity controls global processes." No evidence is presented that ecological complexity is measurable, or that it has anything to do with global processes (beyond the truism that prokaryotes are necessary for many biogeochemical cycles). It seems to be the very large questions of SBI that suffer most from resting on assumptions that are either not literally true or not well defined. As SBI lists specific research questions (1992: 399–401) the metaphorical nature of the assumptions is less conspicuous.

Many of the SBI goals have been reiterated ever since some biologists self-consciously called themselves ecologists in the first decades of this century (McIntosh 1985). Ecologists do not reinvent the wheel but when gathered in committees they do seem to revive grandiose dreams. Ludwig et al.'s (1993) comments are perhaps best seen as a cry for awakening to the fact that not only specific theories but also institutional goals are in part based on literally empirical assumptions. If these assumptions are poorly formulated or not empirically valid, assertions about goals become more poetry than science.

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SUSTAINABILITY AND ECOLOGICAL RESEARCH[1,2]

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We address three aspects of sustainability: the concept, the feasibility of attaining it, and the relevance for ecological research. In addition, we address the role of scientific consensus, an issue also raised by Ludwig et al. (1993).

The Concept

There are three forms of "sustainability" in wide use: sustainable use, sustainable growth, and sustainable development.

If humans use living components of ecosystems (renewable resources) in ways that allow natural processes to replace what is used, the system will renew itself indefinitely and human use will be "sustainable." This has sometimes occurred in cases in which people have used resources for long periods of time without degradation (e.g., in western Amazonia, coastal northwestern North America, northern Australia); often such practices have been tied to strong cultural beliefs. Few, if any, examples exist of long-term sustainable use by modern industrialized societies and even nonindustrial societies have not always been successful in sustaining exploitation of a resource, particularly when new areas have been colonized. How modern societies can live and prosper "sustainably" on the planet is *the* greatest challenge facing humankind and ecology is essential to addressing this challenge.

Next consider the term "sustainable growth," par-

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

ticularly its implications with respect to the limits of resources. Growth in human population and growth in per capita resource consumption and the associated habitat degradation often happens without recognition of the finite nature of the Earth's resources. A basic question concerning "sustainable growth" is whether economic growth can be sustained without population growth, growth in consumption of resources, or continued destruction of habitat.

A common and widely publicized term these days is "sustainable development." Part of the reason for its prevalence is that it can be defined in a variety of ways and, in fact, it is usually undefined. Sustainable development can mean sustainable use, in which case it is an imperative; it can also mean sustainable growth of population and resource consumption, in which case it is impossible. Unfortunately, unregulated growth in quest of "sustainable development" undermines the potential for real economic and social improvement that can be fostered by sustainable use of renewable resources (see Norse 1993 for examples).

The Feasibility

Ludwig et al. (1993) stress the importance of the interaction of economic and biological factors. Colin Clark's (1973, 1976, 1990) insights in this area are particularly revealing and the transition in the two editions of Clark's book is noteworthy. The first edition is essentially a completely deterministic treatment of the problems of resource exploitation, while the second edition deals with uncertainty and stochasticity, thus confronting the uncertainty, as described by Ludwig et al. (1993). Even within a solely economic context, we can see the importance of uncertainty. Fluctuations in economic factors such as the interest rate will cause perspectives on conservation to change: About a dozen years ago, when U.S. interest rates were $\approx$14%, a sole owner of a resource growing at 8% would have great incentive to eliminate it and reinvest the capital. The situation is very different today. Sustainability is unlikely in a system in which one can easily liquidate low-interest investments in living resources (such as blue whales) for higher interest investments in nonliving resources (such as financial markets).

We must also consider biological factors. Much of the thinking about sustainability has been based on the logistic equation or some variant of it. Discussion of the suitability of a logistic model usually focuses on either the particular form of the density dependence or on adding some kind of stochasticity to the model. Seldom are either the fundamental underlying hypothesis of intraspecific population regulation questioned or alternatives investigated. For example, claims of sustainability using a logistic model assume that the stock can recover from any level of depletion and that the only major causes of decline will be removal by humans or internal, density-dependent mechanisms. Even the more complicated management models, including those with age structure such as the "Hitter-Fitter" used by the International Whaling Commission, implicitly adopt the view that internal, density-dependent mechanisms regulate population structure.

However, it is highly likely that many local populations of exploited species are not closed and regulated by internal, density-dependent mechanisms, but are regulated by external physical and biological factors such as environmental catastrophes and immigration. An alternative to the logistic-based description of an exploited stock is one in which the population is sustained by recruitment, possibly independent of population size, and in which local changes are caused by individual births and deaths and by environmental shocks or catastrophes (Mangel and Tier 1993). In such a case, the meaning of sustainability requires new and vigorous investigation.

Even where target species appear to be taken sustainably, a closer look can reveal important and unexpected consequences. For example, the current worldwide take of penaeid shrimp might be sustainable, but an estimated 80–90% of shrimp trawlers' catch are nontarget species (Andrew and Pepperell 1992). The best studied of species taken incidentally are sea turtles, including the endangered Kemp's ridley (*Lepidochelys kempi*) turtle, which has experienced a 99% reduction in population size since 1947 (Pritchard 1990), largely due to drowning in shrimp trawls. Population declines of other species taken incidentally in the shrimp trawl are far less likely to be noticed.

Seemingly sustainable exploitation of one species can have profound consequences at both ecosystem and genetic levels. Before the introduction of horses and guns, Native North Americans might have taken bison (*Bison bison*) sustainably for millennia by using fire to boost and attract bison populations, which changed forest ecosystems to savanna or tallgrass prairie over huge areas. Concerning genetic changes, an intriguing case (Power and Gregoire 1978) occurs in Quebec, Canada where some lakes have landlocked harbor seal (*Phoca vitulina*) populations. Lakes with and without seals have brook trout (*Salvelinus fontinalis*), but size-selective predation has led trout to mature at much smaller sizes (and to the complete absence of larger sizes) in lakes having seals. Exploitation of biological resources by humans in other systems will surely lead to similar kinds of changes.

Talbot (1990) and Botkin and Talbot (1992) discuss failures to and/or the inability to achieve sustainability of tropical moist forests, tropical dry forests, and temperate forests in terms of ecosystems, timber yield, biological diversity, and other factors. Among other points, they (Botkin and Talbot 1992) conclude that (1) even aside from consideration of sustainability of entire ecosystems and biodiversity, sustainability of yield alone has been achieved in tropical moist forests only a small fraction of 1% of the time at best; (2) they are not aware of the sustainability of any original forest under commercial harvest having been documented; and (3) the sustainability of yield, even in a disturbed forest, has been rarely achieved.

At best, sustainable use of a single exploited stock takes a combination of detailed understanding, exquisite care of the ecosystem, and good luck. Moreover, apparently sustainable exploitation can have profound effects on genetic, species, and ecosystem diversity. Determining and predicting the consequences of such changes is clearly an important role for ecological science.

The Role of Scientific "Consensus"

We believe that a principal reason for the routine overexploitation of resources is that the scientific community often fails to differentiate between science and policy, that is, to separate fact and value judgments. For example, scientists are often expected to reach a "consensus" amid considerable uncertainty about cause and effect. Instead of telling policy makers that they cannot accurately predict the consequences of alternative management strategies, scientists allow themselves to be forced into negotiated agreement. As a result, decision makers (usually not trained as scientists themselves) are often not fully aware of the uncertainties and cannot be held fully accountable for the consequences of their actions.

The International Whaling Commission, for example, asks its Scientific Committee to recommend catch quotas. Available information is often insufficient to determine catch levels that can be sustained, and many Scientific Committee members have different views about what should be done in the face of uncertainty; some believe that, when there is uncertainty, the benefit of the doubt should be afforded to the industry while others believe it should be afforded to the resource. Instead of reporting the uncertainty and the possible consequences of this uncertainty to the Commission, the Committee generally has sought "scientific consensus" that represents a middle ground. In hindsight, the consequence of attempting to reach a consensus is clear: one stock after another of the world's large whales have been driven to economic and near biological extinction.

The continuing "scientific" debate concerning global warming provides another example. The available data are equivocal and there is no scientific consensus on the rate or the geographic pattern of warming. The result is that decision makers (and the public at large in this case), aware of the substantially different views of the scientific community, usually take the course of least immediate social, economic, and political cost. More responsible and ecologically sound decisions would probably result if scientists clearly identified the uncertainties and the possible consequences of alternative actions in the face of those uncertainties, rather than try to reach a consensus on what is true or not.

The Relevance for Ecological Research

Ecology is a complex subject, involving many types and scales of temporal and spatial interaction. Because a fundamental problem of ecology (basic or applied) is how organisms persist in their environments, ecological research has much to offer for illuminating the notion of sustainability. Unfortunately, decisions on resource exploitation are usually based on short-term goals, and research funding also operates within time horizons too short to determine whether variability in populations and ecosystems are natural or human caused. Some of the problems contributing to overexploitation and habitat destruction might be avoided if research and management programs looked beyond the 2–6 yr political time frame and tried to match the rate of use to the degree of uncertainty.

To maintain biological diversity and options for a sustainable future, societies need to shift the burden of proof from demonstrating that ongoing or planned activities will damage or destroy the resource and have adverse socioeconomic consequences, to demonstrating that ongoing and proposed use will not reduce management options 15–20 yr hence.

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