Sustainability and the Scientist's Burden

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Abstract: *Natural scientists are being encouraged by environmental and developmental agencies to define and operationalize the concept of sustainability in a "scientific" manner. Such an approach is fraught with dangers because values, opinions, and social influences are an inextricable part of science, especially applied science. Natural scientists' attempts to define sustainability, particularly to decide what should be sustained, cannot therefore be value-neutral. They simply end up shifting value judgments to different levels by choosing either a single obvious objective, an arbitrary range of objectives, or an arbitrary method of aggregating different preferences. This lack of self-reflectiveness on the part of scientists has important consequences for the direction of research and its political implications. Natural scientists should heed lessons from earlier cases of scientists' involvement in policy and redefine the terms of reference before shouldering their social burden. The dilemma of pursuing objective science in a value-loaded and socially charged discourse can be resolved by properly understanding the role of analysis and by pursuing a socially grounded pluralistic approach to problem definition and research methodology.*

La sostenibilidad y la carga que soportan los científicos

Resumen: *Los científicos naturalistas son incitados por las agencias ambientales y de desarrollo para que definan y operacionalicen de una manera "científica" el concepto de sostenibilidad. Tal enfoque esta lleno de peligros, ya que los valores, las opiniones y las influencias sociales son una parte intrínseca de la ciencia, especialmente de la ciencia aplicada. Los intentos de los científicos naturalistas por definir la sostenibilidad, y en particular para decidir que es lo que se debe sostener, no pueden por lo tanto ser neutrales. Los juicios de valor son simplemente cambiados al escoger un objetivo único "obvio," una serie arbitraria de objetivos o bien un método arbitrario de agregación de diferentes preferencias. Esta falta de auto-reflexión por parte de los científicos tiene consecuencias importantes en la dirección de la investigación y para sus implicaciones políticas. Los científicos naturalistas harían bien en prestar atención a las lecciones de los casos anteriores de implicación de científicos en la politica y en redefinir los términos de referencia, antes de echarse sobre la espalda la "carga" social. El dilema de buscar una ciencia objetiva en un discurso cargado de valores sociales puede resolverse mediante una apropiada comprensión del rol del "análisis" y mediante la búsqueda de un enfoque social pluralista en la definición de los problemas y en la metodología de la investigación.*

For three centuries the ideas of progress and growth, with science as their driver, have been the organizing concepts in Western understandings of the future. During the past decade, however, the notion of sustainability has begun replacing these ideas in domestic and global discourses. Serious attempts are now afoot to put this notion on a sound, "scientific" footing. Given the environmental origins of the concept of sustainability, natural scientists have become the primary focus of these attempts. At numerous conferences they are being asked to translate this rejuvenated concern for the future into specific definitions, criteria, and indices. One such conference opened with this typical call to scientists to "agree on a *scientific* definition of bio-

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Paper submitted October 17, 1994; revised manuscript accepted May 15, 1995.

physical sustainability. . .[and] to recommend. . .a *scientifically sound* and practical index of biophysical sustainability. . .the ecological equivalent of the Gross National Product. . . [that] reflect[s]. . .net primary productivity, biological diversity and perhaps other factors" (De Souza 1992, emphasis ours).

Scientists are responding to the call. The number of articles listed in the Current Contents index with "sustainable" or "sustainability" in the title increased from 60 in 1989 to 286 in 1992, most of them in the biological or physical sciences. *Ecological Applications* published a special forum on the topic, prefaced by an editorial that characterized sustainability as "the central environmental issue facing us" (Levin 1993). The Ecological Society of America has proposed the Sustainable Biosphere Initiative (SBI) as the ecological research agenda for the 1990s (Lubchenco et al. 1991). The International SBI (Huntley et al. 1991) and the numerous other research initiatives have followed.

All parties in the evolving global discourse on sustainability acknowledge that, at the broadest level, the concept rests on a certain world view and a certain value judgment: the view that our descendants' well-being may not be as guaranteed as we historically presumed, and the judgment that we *should* care about their well-being. All agree also that this well-being is at least partly determined by the natural environment, hence the call for its sustainable management—for ecological or biophysical sustainability. The challenge is perceived by some as a matter of bridging these moral and managerial meanings of the term. Brooks (1992), for example, argues that "For the concept of sustainability to be operationally useful. . .it should be defined so that one could specify a set of measurable criteria such that individuals and groups with widely differing values, political preferences, or assumptions about human nature could agree whether the criteria are being met in a concrete development program."

Brooks' call highlights a crucial dilemma. On the one hand, measurable, objective, value-neutral criteria seem necessary for effective action. Environmental, resource, and development agencies at all levels of government seek such criteria so they can do their work without constantly being held up by the politics of value choices. On the other hand, world views and values seem to be integral to the concept of sustainability. The change in world views of the future is not universal; many retain their technological optimism, whereas others disagree about the level of eco-pessimism that is warranted. Some people may not or cannot care as much about the future as others. More important, among those who do and can, there are differences over what kind of a future is desired and what should be sustained. In the midst of this quicksand of values and world views, how might the natural science profession best shoulder its social burden?

Having confronted this dilemma in our own research (Lélé 1993*a*; Norgaard 1994), we became intrigued with how natural scientists have tried to define and operationalize sustainability. Our findings are summarized in this paper. We begin by elaborating the nature and scope of the value judgements in and social influences on sustainability science. Scientists have typically sought to circumvent rather than confront these issues. We characterize three such stances commonly adopted in the natural science discourse on operationalizing sustainability and discuss their scientific and social implications. Underlying these stances is the belief that an objective—or at least consensual—definition of sustainability is both necessary and possible for research on it to proceed. We argue to the contrary on both counts and remind readers of how science has been distorted in the past when it accepted similar public burdens equally blindly. We suggest a way of redefining the scientist's burden to ensure both the quality of the science and respect for the values of the people whose future is to be sustained.

Sustainability Questions, Subjectivity, and the Social Context

Is it possible to define and operationalize sustainability in an objective manner? Shorn of specific connotations and nuances, sustainability is simply the ability to maintain something undiminished over some time period. Any definition of the concept therefore requires explicit or implicit answers to three kinds of questions:

(1) What is to be sustained, and at what scale, and in what form?
(2) Over what time period and with what level of certainty?
(3) Through what social process and with what tradeoffs against other social goals?

We argue that individual answers to these questions involve an inextricable combination of value judgments, world views, and consensual knowledge. Moreover, how individual answers are framed and translated into collective action or policy depends critically upon the structure of social relations and institutions in which the science is embedded. Objective or even consensual answers are therefore impossible.

At the outset, values determine whether the objective to be kept undimished should be human material wealth, human spiritual well-being, or the well-being of all living beings. Values also determine whether this well-being should be undiminished over just our lifetime or over many generations. If ensuring future well-being requires sacrificing some current well-being, who should sacrifice and how much are also questions of social values. And there is, of course, a tremendous plurality of these values across individuals and communities. So an additional value judgment has to be made as to what is an acceptable method for resolving these differences.

Translating broad value preferences into prescriptions for action requires an understanding of how natural and social phenomena contribute to human material wealth, spiritual well-being, or the welfare of all living things—in other words, a model of how the world works. The conventional positivist position has been that this model can be constructed in a purely objective fashion, through the application of the scientific method by its unbiased practitioners. The role of values is restricted to deciding what is to be done; science can neutrally specify how to do it. Upon closer examination, however, this watertight separation of science, self, and society springs a number of leaks.

First, our knowledge is incomplete. Although scientific research has led to a near consensus about some aspects of the inquiry, it by no means provides a single, complete image of the relationship between society and nature. Our models of the world *always* consist of some consensual "knowledge" about specific aspects with more subjective guesses about others, and world views about the larger system. Furthermore, these broad world views, or even specific choices made in face of scientific uncertainty, are not randomly distributed but are correlated with individual values, disciplinary biases, and positions in the social order. Techno-optimists are often techno-freaks, whereas eco-pessimists are more likely to be Spartans. Population biologists tend to look at even human communities in terms of *r*- and *k*-strategists, whereas political scientists analyze even intimate personal relationships in game-theoretic terms. And the controversy over calculating the global warming potential of greenhouse gases illustrates the influence of social position. In the face of great scientific uncertainty, some U.S. scientists have adopted a method that shifts more of the responsibility for the greenhouse effect onto developing countries than other methods would have (McCully 1991). It now appears that the methane emissions from paddy fields (overwhelmingly located in the developing nations) have been exaggerated by scientists from developed nations (Anonymous 1995).

The separation of science, self, and society becomes even more porous when one examines the nature of scientific thinking itself. Scientists proceed to map reality by adopting broad images and then formulating specific analytical constructs—models, variables, and scales—to test the details. Choosing the broad image, or framework, requires making *a priori* decisions about which factors matter, how they probably interrelate, and how to bound the analysis. Different frameworks stress different factors, pay less attention to others, and totally ignore most. A coevolutionary framework emphasizes ecosystem change, whereas a Clementsian framework assumes that stability is the ultimate goal toward which ecosystems (unconsciously) strive. A decision to take an energetics approach to ecological research on a marsh will emphasize the productivity of the system, whereas a community ecology approach will emphasize species interrelations and diversity.

Even within a particular framework or approach, the variables and units are not "naturally" determined. In studying the productivity of a forest one must decide whether to measure the rate of photosynthesis, the annual increment in standing timber, or the increase in protein content of the edible plants and animals it harbors. Each variable has different units (calories, tonnes, and protein grams) that are incommensurable, at least without additional subjective assumptions, and the factors determining the behavior of each variable overlap only partially. Hence, predicting each variable requires using a different model, and these individual models cannot be incorporated into some meta-model. Each model is useful in its own context, corresponding to the needs of different users of the forest: climatologists, timber companies, or hunter-gatherers. Thus, the question "models of what?" becomes "models for whom and by whom?"; individual preferences get linked with social differences.

In short, simply to think, we must simplify: choose, eliminate, and aggregate. Different simplifications imply prior judgments as to what is important, judgments that people with different upbringings, disciplinary backgrounds, or positions in the social order will disagree with or dislike. And because environmental problems are by nature complex and open-ended, affecting diverse peoples in a highly fragmented, changing, and unequal social order, the choices of frameworks, variables, and scale in the environmental sciences are likely to be especially contentious. Individual and social values and the sociocultural factors that shape them thus appear to be embedded at every level of the sustainability discourse—goals, world views, models, and variables—making scientific definition impossible.

Most people, especially agencies charged with implementing sustainability and scientists brought up in the positivist tradition, are uncomfortable with this characterization. To them an objective definition of sustainability is both necessary and possible. Sustainability needs to be defined by scientists because, as Jasanoff (1992) puts it, "science, [with] its still potent claims to value-neutrality, promises to provide the only forum where nations [or other communities] can set aside their political and cultural differences in favor of a common *rationalistic* approach to problem solving" (Jasanoff 1992; emphasis ours). Rooted as they are in conventional positivist thinking about the relationship between science and society, scientists seem to think that an objective or at least consensual definition can be arrived at by working simultaneously to narrow the list of desirables and the list of possibles. The first is achieved through a value-minimal approach. Brooks (1992) writes:

> The usefulness of the sustainability concept depends upon the degree to which it can be formulated in a relatively value-neutral way. . . . This does *not* mean that values are unimportant. But, since sustainability is about the future, and we cannot foresee the values of our descendants, we need to focus primarily on those attributes of policy that determine man's survival as a species.

At the same time efforts have begun to bring about a convergence of scientific opinion on the nature-society relationship, the severity of current stresses on it, and the extent of its flexibility. Such a convergence would complement the value-minimalist approach because it would point to a single direction and agenda for action regardless of whether one wishes to ensure just the survival of the human species or any larger set of values. The attempts by natural scientists to operationalize sustainability differ essentially in the extent to which they perceive such a convergence of goals and options.

The Natural Science Response

Most of the sustainability discourse has focused on the first question: "What is to be sustained?" For the natural scientist (typically positivist and convergence-seeking), the question becomes "What attributes of nature should be sustained in order to sustain human well-being, however this may be defined?" Broad answers such as "sustain the biosphere" (Clark & Munn 1986; Ludwig 1993) are easy, but the devil is in the details.

The SBI's attempt to specify "sustaining the biosphere" as "[coping with] global change, [conserving] biodiversity, and [maintaining] sustainable ecosystems" (Lubchenco et al. 1991) illustrates how recursiveness is an ever-present danger. Others variously call for the maintenance of "the character and naturalness of ecosystems" (New Zealand Ecological Society) or of "biodiversity and ecosystem integrity" (Robinson et al. 1990; Botkin & Talbot 1992), "biological quality" (Goodland et al. 1990), "biological integrity" (Angermeier & Karr 1994), "ecosystem health" (Costanza et al. 1992), and "natural capital" (Costanza & Daly 1992). Although loose semantics and operational vagueness make exact distinctions difficult, we see three broad categories in the various approaches:

(1) those that adopt naturalness as the "obvious" and hence universally acceptable objective;
(2) those that identify "fundamental" variables that determine the ecosystem's capacity to cater to the range of desires society may have of it, and
(3) those that try to "scientifically" reconcile or aggregate various human desires and perceptions into societal decision making.

We discuss these approaches and expose the nature of the hidden value judgments in them and the consequent real-world complications predicted in our framework.

Ideology of Naturalness

In a working group set up to define sustainability at the international conference inaugurated by de Souza (1992), an eminent scientist suggested that maintaining Earth's natural processes and biodiversity was *inherently good*, even if there were no human beings on the planet to benefit from these phenomena. Although this position may sound absurd when presented so baldly, it is not significantly different from the claim that "the continued existence of the natural world is inherently good" (Robinson et al. 1990). Both of these are ethical arguments for maintaining "naturalness" or "pristineness."

Others give apparently pragmatic arguments for doing so: natural states provide the only objective basis or benchmark for assessing biological integrity (Angermeier & Karr 1994). Or they simply define ecological sustainability with reference to "non-harvested natural populations" (Hall & Bawa 1993) or "biological quality and ecosystem services . . . of natural forests" (Goodland et al. 1990), without bothering to explain why natural population levels or community compositions are sacrosanct. To them, naturalness is the obvious benchmark.

This consecration of the natural is widespread in Western environmentalism and in the environmental science backing this "ism." It stems from the "European [or Romantic] notion that wilderness is defined by the absence of human influence" (Clarke 1993). This notion probably inspired and was in turn reinforced by the Clementsian picture of all ecosystems reaching a stable climax. When adopted unconsciously, however, it results in a range of logical and practical problems.

First, natural systems may provide an objective basis for assessing biological integrity, but the use of biological integrity as the primary objective of conservation policy (Angermeier & Karr 1994), or the more general view of natural systems as inherently good, is clearly a value judgment. Second, there is the logical paradox that naturalness or wilderness cannot be valued in the absence of human beings to value it, but human presence is bound to make the world unnatural. Third, the use of naturalness as both means and ends creates tautologies (and uninteresting ones at that), leaving little room for empirical validation. In the framework of Angermeier and Karr (1994), natural systems provide an objective basis for assessing biological integrity simply because biological integrity is defined as a condition of "little or no influence from human actions. . .reflect[ing] natural evolutionary and biological processes." Similarly, by defining sustainability in terms of the quality of and services from natural forests, Goodland et al. (1990) arrive at a sustainability ranking of land-use regimes (intact forests > tree plantation > agri-silviculture > agriculture, (where > means more sustainable) that is true by definition, but not supported by (or requiring) evidence.

If, instead, one were to adopt the common-sense notion of sustainability as the probability of any particular state (measured in different terms) simply lasting over time, such claims could be empirically examined. And such examination might raise some uncomfortable issues for this ideology. On the one hand, there are many examples of human-managed systems that have lasted in a productive state for hundreds if not thousands of years: indigenous systems of terraced cultivation in Asia and wildlife management in east Africa are two examples. On the other hand, the identification of "natural" benchmarks is a difficult if not impossible proposition, given the inherent spatial and temporal variability in ecosystem behavior and structure and the long history and ubiquitousness of anthropogenic disturbance (Denevan 1992).

This ideology has nevertheless exerted a strong influence on the direction of ecological research. Pure research has tended to be focused on or conducted with reference to "pristine" ecosystems, whereas the dynamics of more "disturbed" ecosystems such as historically used forests and rangelands are ignored or left to applied researchers. For instance, Lugo and Brown (1984) remark on the tendency to dismiss "fallow and secondary forests [as] worthless brush" and the consequent paucity of research on these ecosystems compared to that on undisturbed rainforests.

The social implications of this bias go beyond simply skewing the direction of scientific inquiry. In the real world, an ethic that respects all natural beings and processes becomes distorted into one that rejects the less privileged of its own kind. Use is pejoratively termed disturbance, which is simple-mindedly equated with degradation. The obvious policy then is to police, and the costs of preserving naturalness are dumped with curious regularity upon the nature-dependent rural poor. Indeed, it is the practical unsustainability of these "police and prohibit" policies, with their high economic and political cost, that is now forcing a broadening of the discourse.

An Objective Basis of Subjective Well-being

As the environmental discourse has shifted from preservationism to sustainable development, the idea that pristineness is not necessary, that ecosystems managed by human beings can also be sustainable in some sense has become more acceptable to many natural scientists (McNeely & Pitt 1985). These scientists have therefore directed their efforts toward identifying a set of fundamental, essential, or integral variables and their "sustainability thresholds"—those biophysical limits that cannot be violated without causing harm to long-term human well-being (however conceived). The terms "ecosystem integrity" or "ecosystem health" were originally used solely with reference to natural conditions, but they have evolved into lists, composite indices, and theories of features that enable the ecosystem to reproduce some essential characteristic(s) (Schaeffer et al. 1988; Costanza et al. 1992; Amir & Hyman 1993). Scientists are now arguing about which of these terms will become the operational expression of sustainability in the natural sciences.

The question is whether this approach will finesse the problem of value judgments. The proponents of this approach appear to believe so. For instance, Franklin (1993) defines sustainability of forest ecosystems as "the maintenance of the potential. . .to produce the same quantity and quality of goods and services in perpetuity." He emphasizes "potential. . .since it [provides] the option to return to alternative conditions rather than focusing exclusively on current conditions." He then identifies "productive capacity" and "genetic potential" as the operational forms of productive potential. In other words, productive and genetic potential are scientifically determined variables that, if sustained, can ensure alternative forms of well-being.

We argue, however, that the problem of value judgments is not really obviated but is simply relocated. First, if we allow that the conditions for maintaining some levels of productive capacity can conflict with conditions for maintaining some levels of genetic potential, the question of what levels of each to maintain remains. Second, there will always be a limit to how many alternative conditions or resource-use objectives the fundamental variables can accommodate. For example, soil nutrients are fundamental to sustaining both timber production and wild habitat, but are they relevant if the land is to be used for house construction? Even if one restricts the discussion to only vegetative land-uses, the soil variables—depth, significant nutrients, microbes, etc.—and their threshold values relevant to maintaining, for example, timber production are likely to be different from those relevant to maintaining productivity of agriculture on the same land. Finally, if Franklin's formulation is implicitly limited to the context of forested ecosystems, the question of how much forest to maintain vis-a-vis nonforest remains. Or does sustainability require no change in the current land-use pattern?

In other words, although minimizing the number of variables needed to explain ecosystem behavior across a wide range of conditions is the essence of science, *which* aspects of ecosystem behavior need to be explained is always a subjective choice directly or indirectly shaped by society. As Levin (1992) points out, "essential features cannot be defined without reference to a set of external valuations of the system." For instance, while ecologists equate production in a forest with net primary production, foresters think of production as "net biomass increment," often leading to confusion (Satoo & Madgwick 1982). Furthermore, villagers utilizing that forest as a source of timber, fuelwood, fodder, and leaf manure might characterize "useful" production in yet another way. Failure to recognize these professionally and socially constructed differences has led to confusion. Foresters' estimates of useful production in village forests have consistently left out branch, leaf, and litter production, leading them to conclude that villager extraction exceeds production and hence is unsustainable (Lélé 1993*a*; Lélé 1994).

In practice, the external valuation provided by society are not simply an incoherent cacaphony, but are often determined by the loud and powerful. Scientifically chosen indicators are not just subjective; they reflect the biases of a necessarily urban, often Western or certainly Westernized scientist working with funds provided by agencies with their own agendas. The history of tropical forest research, for instance, shows a strong correlation between what is considered essential by the owners (as opposed to users) of the resource and what is considered worthy of research by scientists (Guha 1985). Similarly, the biologist's bias toward biodiversity gets manipulated and used to lobby for global treaties that reserve tropical forests for exploitation by multinational pharmaceutical and biotechnology companies at the expense of rural communities who live in, depend upon, and have conserved these forests.

Ideology of Aggregate Global Indices

Some natural scientists, exposed to the multi-objective world of resource policy, have sought to reconcile these differing societal preferences. This approach embodies the notion of "rational decision-making [that] balance[s] the risks and benefits of a variety of possible outcomes" (Hilborn & Ludwig 1993). Its specific form depends upon the scale of interest—micro or macro—in a manner similar to the project scale or national/global scale in economic analysis.

At the micro scale the call is for a "scientific assessment of total short- and long-term costs/benefits" of alternative projects (Ehrlich & Daily 1993). At the macro scale the call is for a "scientifically sound global sustainability index . . . the ecological equivalent of the Gross National Product (GNP)" (De Souza 1992). Such an index has already been outlined by some ecological economists under the rubric of "natural capital," defined as "the stock of natural resources such as soil and soil quality, ground and surface water and their quality, land biomass, water biomass, and the waste assimilation capacity of receiving environments" (Pearce et al. 1988:6).

Why should natural capital be sustained? Pearce et al. and other authors have argued that maintaining natural capital is a necessary and sufficient condition for the sustainability of human well-being in two senses of the term: equilibrium under average conditions and resilience under catastrophic conditions (Pearce 1988). Environmental economists have therefore urged for and worked toward the modification of the systems of national accounts, which currently measure conventional GNP, so that they account for changes in this natural capital (Repetto 1986; Harrison 1989; Lutz 1993). The policy prescription for achieving sustainability is also straightforward: tax human activities in proportion to their depletion of natural capital (Costanza & Daly 1992).

Whether conserving this natural capital ensures equilibrium and resilience is outside the scope of this paper (see Lélé 1993*b*). The question here is how natural capital or other sustainability indices deal with the problem of value judgments. In addition to the choice of scale, any such index involves the use of some relative weights to aggregate its individual elements—such as resources and assimilative capacities—into a single number. It seems reasonable that the weights should be in proportion to each element's contribution to human well-being. But how can this contribution be measured objectively if notions of well-being vary vastly across individuals and communities?

Welfare economists confronted this problem decades ago when estimating the total costs and benefits for a project or the GNP for an economy. They accepted the use of the market prices as weights for economic goods and services, arguing that, under certain conditions, such as perfect markets, these prices reflect the aggregate of a society's preference for a particular good relative to another. The proponents of natural capital have adopted essentially the same approach, except that, because markets do not exist for many environmental goods and services, different techniques for estimating "shadow" prices or equivalent market value need to be developed. Indeed, valuation of environmental goods and adjustment of systems of national accounts (Mitchell & Carson 1989; Jansson et al. 1994) constitute the dominant themes in the emerging literature on ecological economics.

A moment's thought would indicate, however, that the choice of market prices for aggregating individual preferences into a social choice is arbitrary. It is based on the assumption that the well-being derived by two persons from consuming a unit of a particular good is the same if they are both willing to pay the same price for it. But this assumption has no logical basis. Indeed, "we cannot even be certain that group *A* is better off than group *B* even if *A* has collectively more of everything" (Bromley 1990, citing Paul Samuelson). More generally, there is no objective procedure for aggregating individual preferences (or for agreeing upon a procedure for aggregation); the market is as arbitrary a means of social choice as a referendum (Arrow 1974). Thus, to insist that natural capital can be an objective indicator of aggregate sustainability is akin to insisting that GNP is an objective indicator of well-being in a country. One is simply shifting the value judgment from the choice of sustainability objectives to the choice of valuation and aggregation procedures.

Welfare economists have long ignored this problem of values, despite repeated pointers, criticisms, and pleas even from within their own profession (Kapp 1950; Blaug 1980; Nelson 1987; Norgaard 1989*b*; Bromley 1990). It is rather ironic, however, that natural scientists, in their quest for a rational decision-making process, should also ignore interpersonal issues. The only situation in which such comparisons are not required is that involving a single-resource, a single-owner, and no externalities. But the main contribution of natural science to the environmental discourse—indeed, the *raison d'etre* for this discourse—lies in its demonstrating the interconnectedness of natural ecosystem processes across space, time, and uses—in other words, the pervasiveness of spatial, temporal, and sectoral externalities (Lee 1993; Lélé 1993*b*).

The practical consequences of this ideology of aggregate global and national indices are far-reaching. Indices by nature are simple-minded (increase is good; decrease is bad), whereas reality is not (for instance, increases in standing stock of a forest initially increase but later on decrease its timber increment). Global or national scales are inappropriate for many environmental phenomena; the same rate of soil erosion may mean very different things in different parts of a country. The generic index approach thus makes the decision-making process more opaque and more technocratic, because it arrogates to the technocrat the fundamentally political function of deciding on relative weights and scales (Stirling 1993).

Within this broad approach, the dominance of the price-based method is particularly debilitating for science and dangerous for society. First, the use of existing prices to compute indices for guiding policy ignores the important possibility that what may be required is a drastic shift in prices (Norgaard 1989*b*). Second, this method subtly promotes the monetary ethic, which values nothing unless it can be bought or sold and which holds that everything has a price. Third, and perhaps most important, because prices are determined by the distribution of rights to resources, capital, and the fruits of one's labor, valuations based on existing prices reflect and reinforce the existing distribution of these rights—the status quo. In this one-dollar-one-vote method of decision-making, the preferences of the rich automatically override those of the poor because the rich have more votes in the market, whether real or shadow.

Consequently, it is considered rational to convert tropical forests into parks that exclude any human disturbance because rich tourists can pay more for pristineness than local communities can for subsistence use of these forests. The dumping of pollutants from developed to developing nations is also "welfare-enhancing" in the eyes of World Bank economists (Anonymous 1992). "Compensatory afforestation," wherein CO_2 emissions by affluent countries are offset by fenced-off tree plantations in poor ones, is already considered more efficient than the reduction of fossil fuel consumption by the affluent (Dixon et al. 1993). Thus, although all aggregative procedures are arbitrary, the procedure that is ultimately chosen favors the dominant social groups, the very groups that are arguably most responsible for the environmental crisis (Agarwal 1985; Redclift 1987).

Chimera of Value Neutrality

Natural scientists have pursued their quest for a value-neutral definition of sustainability objectives either by choosing certain objectives (naturalness) as "obviously" appropriate, by identifying "fundamental" variables that cater to a broad range of objectives, or by "rationally" aggregating diverse objectives into one index. Our deconstruction of these approaches, however, indicates that none of them achieves the goal of value neutrality or even value minimality. Naturalness as the benchmark is neither value-free nor logically or practically usable. Scientific opinion can converge on a set of essential variables only within a narrow and arbitrarily limited context. Aggregating society's exasperatingly varied preferences into a simple, single sustainability index requires making judgments about the method and scale of aggregation. And at any scale, even with similar preferences, the interconnectedness of environmental processes will create situations in which one person's well-being is sustained at another's cost. The blind attempt to produce value-neutral science only produces research biases and political repercussions that typically favor the haves over the have-nots. Thus, if scientists are to respond to the call to operationalize sustainability, they seem doomed to lose their halo of objectivity and political neutrality.

Perils of Assuming the Scientist's Burden

Given many practical successes of the modern scientific method, it is natural for societies to call upon scientists to help resolve dilemmas and indicate the way to preferred futures. But, as we have seen, the calls and the typical responses tend to blur the line between science and advocacy. Indeed, this is not the first case of society's summons and scientists' response. Over the last century scientists have responded to calls to define environmental health and risk, to improve agriculture, and to manage fisheries, forests, and wildlife. The parallels between these earlier cases and the current call for a science of sustainability are interesting and instructive.

At the end of the last century, scientists began to respond to the call to establish safe standards for public health, food, and—eventually—the environment. Society, and probably scientists themselves at the time, presumed that human and ecosystem responses to contaminants had identifiable and consistent thresholds. Below the thresholds, people or ecosystems would not be affected; problems would appear only above the thresholds. Thus, such thresholds would provide objective measures for contaminant standards. Having accepted the burden of identifying objective standards, scientists soon found themselves providing standards even where no thresholds existed. This proved increasingly contentious as various interest groups acquired their own scientists who pointed out that few thresholds exist and that these are neither constant nor independent of other stresses and contaminants. Today, "regulatory science" continues to have an important public role, but it is crippled by the dichotomy between facts and values on which its integrity depends. Consequently, it is neither well respected by academic scientists nor particularly effective as a policy tool (Jasanoff 1990).

Modern agricultural science started with the call to make "two blades of grass grow where one grew before." In the U.S., special funding mechanisms, government research laboratories, agricultural colleges, and linkages between them were set up during the last century at a time when increased productivity was widely valued. World views at the time conflated the truth of science with the true path of progress and the productivity of new technologies with the public good (Keohane 1982). More and bigger was better, and was achieved in agriculture through a strategy based on heavy application of agrochemicals, intensive breeding, and ambitious irrigation engineering. Since then, basic agricultural science has shifted toward thinking of whole ecosystems rather than individual species, the public's concern has shifted from physical productivity to social and environmental quality, and our faith in technological progress has been severely tested. The heroes of the green revolution are now the villains because they responded to or heard too narrow a call, established too limited a set of indicators of success, and set up institutions that reinforced particular values and world views, with significant adverse consequences for agriculture, environment, and community (Dahlberg 1986; Gall 1992; Norgaard 1992; Office of Technology Assessment 1986).

Especially familiar to readers of this journal is the case of wildlife and fisheries management. In the U.S., norms for training and research in these areas were established at the turn of the century and bolstered by related professional and scientific organizations. Management was species-specific and directed to the interests of hunters and fishermen. A century later in 1985, however, the Society for Conservation Biology was founded largely by biologists "to help develop the scientific and technical means for the protection, maintenance, and restoration of life on this planet. . . ." These new scientist-activists find the earlier management objectives (maintaining game instead of wilderness) inappropriate, scales (species instead of communities, landscapes, and ecosystems) too small, and research institutions too old-fashioned, even "unscientific" (Hobbs & Huenneke 1992; Meffe 1992; Temple 1992). As in the case of modern agriculture, those who earlier assumed the burden of scientific conservation are now being accused by academics of doing poor science and by activists of being a part of the problem.

Our brief historical exploration indicates that the difficulties associated with socially relevant science are not new. Whether in the case of environmental health, agricultural science, or wildlife management, the callers and the respondents have—naively or duplicitously—passed off value judgments as objective truths. More precisely, they have been less than fully self-conscious and transparent about the necessarily subjective choices being made, the domain in which and process by which they ought to be made, and their social context and consequences. The result has been a narrow and inevitably biased choice of assumptions, variables, and methods. Where this subjectivity has gone unnoticed or unchallenged, social outcomes have been lop-sided and reinforced the status quo. When challenged, applied scientists have lost the respect of their academic colleagues and the confidence of activists, and the policy process has become a morass. Natural scientists seeking to respond to the new call to define and operationalize sustainability would do well to take heed of this history of policy research, to redefine the scientist's burden before shouldering it.

Redefining the Burden

We have argued that values are an inextricable part of defining and operationalizing sustainability, so an objective sustainability index can be defined only with reference to specific objectives and specific world views. But objectives, values, and world views differ from person to person, community to community. How then does one conduct useful and yet scientific research on sustainability?

At a minimum, scientists could accept the inevitability of making value judgments in the process of their research. They could therefore make the value judgments currently implicit in their methods explicit (1) to the affected communities prior to undertaking research and (2) to all potential users of the scientific results or opinions stemming from the research. Such self-reflectiveness and openness is not entirely absent today; occasionally, papers do begin with an outline of the values, world views, and communities privileged by the chosen definitions and variables (e.g., Pickup & Smith 1993). If this approach were emulated universally, it would lead to a major improvement in communication between scientists, people of different cultures and interests, and policy makers.

We believe, however, that it is appropriate and timely to take a bolder approach. Our approach embraces the inescapable plurality of answers that scientists have generally tried to dodge and redefines the role of applied science. It may seem like a rigorous reiteration of an essentially positivist perspective, but we hope it will be a Trojan Horse carrying within it the more complex framework about science, self, and society that we espouse.

Approach

The starting point of our redefinition of the scientist's burden is Daniel Bromley's clarification of the concept of analysis in economics:

> To analyze something is not to reduce all of its components to dollar estimates of surplus, or to changes in net national income. . . .[It] is to attempt to understand who the gainers and losers are, how they regard their new situation in their own terms . . . [in short,] to understand the problem from different value perspectives (Bromley 1990).

In the context of sustainability, scientific analysis would mean understanding the likely effects of different resource-use options in terms of different sustainability objectives, time frames, and affected individuals. But one cannot analyze from as many perspectives as there are individuals, so our approach requires the identification of communities of like-minded or like-valued individuals. We suggest that scientists should participate in identifying such like-minded communities, understanding the effects each community might be concerned about, and then analyzing various proposals for sustainability in terms of these various effects. Rather than impose their own perceptions of what should be sustained and for whom, for how long, and with what certainty, it would be less destructive for science and more productive for the policy process if scientists allowed these value judgments to emanate from society.

For instance, an analysis of the sustainability of a typical moist tropical forest ideally would include the following steps:

(1) Identify the different products and services provided by the forest (fuelwood, timber, biodiversity, etc.) and the beneficiaries associated with each village communities, urban consumers, and the global community, respectively), including the manner in which sociopolitical processes shape access to the benefits.

(2) Ascertain the preferences and perceptions of these beneficiaries with respect to the desired products and with respect to time horizons and risk.

(3) Determine the outcome of different forest management options (including changing access conditions) in terms of the magnitude, spatial distribution, and temporal variation of the different benefits and costs for different communities, and possible tradeoffs between them. For example, what are the tradeoffs between fuelwood production, timber production, and biodiversity maintenance? How are the benefits from each distributed across various communities? How uncertain and variable are the benefit flows in each management regime?

Philosophical Implications

From a strictly positivist perspective, this approach is simply a rigorous requirement that researchers look to all of society for guidance in determining the direction and interpretation of their research. If, for instance, society expresses as much interest in production of leafy matter as it has in timber, forestry research will have to encompass both products and the relationship between them. This notion of socially directed, applied research is neither radical nor new. But it bears reiteration when (1) society's ability to oversee the direction of science is diminishing with the increase in scientific complexity and opaqueness, (2) scientists are increasingly either pushed into or actively seeking positions of power in the environmental discourse, or (3) scientists are tempted to push what they know best, which is the direction of their own work, as the right direction for sustainability research (Santana & Jardel 1994).

In implementing this approach, however, one will perforce become more conscious of the inseparability of subjectivity, ethics, and politics from science. At one level, what is meant by "society's preference" in the direction of research? How does one prioritize competing interests? Should one simply go where the funding is, as usually happens, and so acquiesce with the focus on timber in forestry or that on organo-chemicals in agricultural pest control? Or should scientists invoke their rights as another legitimate interest group and inject their own values, as conservation biologists have done with their focus on maximizing global biodiversity, to the exclusion of other concerns? Alternative approaches will subscribe to different value systems, cater to different social groups, and have different social consequences, but they will be no less subjective.

At the methodological level, because each variable of interest brings its own baggage of aggregations, simplifications, models, and methods that often cannot be incorporated seamlessly into some unified meta-model, a true analysis of plural interests requires using different methods and models (Norgaard 1989*a*). A beginning has been made with the acknowledgement of the need for multiple, nonhierarchical, and noncollapsible indicators, "currencies" (Ramakrishnan 1992) and criteria (Lélé 1994) for sustainability. The discourse, however, needs to become more transparent and more self-conscious about the social roots, implications, and relevance of the choices being made.

Keeping this subjectivity and plurality in mind, what can perhaps still be universally attempted is a *process* of research formulation and researcher socialization that actively discusses the social implications of particular scientific choices and trains researchers to elicit social preferences and sense social consequences with as much accuracy as possible. This will require that the current standoff between positivist scientists and postmodern philosophers be replaced by an active collaboration that will push research toward greater interdisciplinarity and social engagement.

Practical Consequences

These considerations have important consequences for the practice of research and for the institutions that drive and use the research. First, if most environmental questions involve competing social interests that are differentially affected through complex environmental processes, if understanding these competing interests and values requires an understanding of social processes, and if understanding how ecosystems affect different interests requires adopting different models, the task of a researcher becomes horrendously complicated. Under these circumstances the smaller the scale chosen, the more likely it will be that the scientist will find communities with relatively homogenous value systems, will adequately understand and interpret these preferences, and will limit the number of environmental variables and processes relavent to them sufficiently to construct a testable model. Such reduction in scale will in turn bring the researcher into closer contact with the communities affected by the research and, if accompanied by the attitudinal changes mentioned above, will help build both rapport and accountability.

Second, if such group-oriented, pluralistic research is to be successful in both the scientific and policy sense, the institutions that support and use such research will also have to become more spatially decentralized, operationally transparent, conceptually pluralistic, and politically broad-based. Far too much of the current demand for research on sustainability is driven by large-scale, closed, technocratic, and hegemonic institutions, such as the World Bank. Admittedly, changing these institutions will not be easy; indeed there is little consensus on the nature and extent of changes needed. But we believe that an honest commitment to enable genuinely plural, socially aware, and locally grounded research can provide the initial impetus for a transition that will eventually become self-directing.

At the same time, we acknowledge the current need to understand sustainability at national and global scales. At these scales, aggregation across peoples with different objectives cannot be avoided. Some generalizations about human values are necessary and will necessarily entail disempowering those people who are the exceptions to the generalizations. To this, our first response is that sustainability is more locally structured than are current research methods and policy processes, so a move toward more local research and policy process is appropriate. Our second response is that the technologies—the means by which people interact with the environment—that are unsustainable over time are the same technologies that make sustainability a globally interconnected problem, by creating externalities over space. As we back away from these technologies, sustainability will become more of a local problem. Third, as we move away from technologies that create large-scale, complex problems across peoples of different values and political capacities, it will be easier to maintain the integrity of science.

Conclusions

Natural scientists have long been involved in the environmental discourse. They have grappled with the tension between their role as objective scientists informing the discourse and as individuals with an interest in changing the world in ways they see as imperative. The discourse on sustainability has heightened this tension because it is simultaneously tempting and treacherous. It includes invitations—nay, appeals—to scientists to participate in the policy process, invitations that are particularly tempting for those who come in daily contact with the impact of human activities on the environment. But it is a veritable minefield of slippery terms and hidden value judgments.

We do not recommend that scientists shy away from their social responsibility—quite the contrary. But accepting the invitations without scrutinizing the terms of reference is a recipe for co-optation and ultimately for nonscience. Scientists need to hear the essential messages of a number of related intellectual discourses. The discourse on environmental science has highlighted the interconnectedness of environmental processes, the consequent inappropriateness of single-user models, and the need to confront the variety of values and effects involved in environmental policy making. The philosophy of science discourse draws attention to the subjectivity and value-ladenness of the scientists' choices of world views, models, scales, and variables. And the sociology of science discourse emphasizes the relationship between these choices and the social structures and cultures in which science and scientists are embedded. It warns against allowing the burden to become another rationalization for imperialism, like its predecessor in Kipling's poem. The greater their self-reflection, cultural sensitivity, and perception of social structures, the greater the likelihood of scientist-activists achieving ethical contentment, social respect, and real-world results.

Acknowledgments

This paper is the indirect outcome of a dialogue begun seven years ago that was sustained and enriched by more individuals than can be mentioned here by name. Nevertheless, we thank Kamal Bawa, Ricardo Godoy, Edward Grumbine, Brent Haddad, John Holdren, Penn Loh, Peter Taylor, William Woods, Jr., and three anonymous referees for their specific and constructive comments. We are also grateful for financial support provided by the Class of 1935 Energy Chair Fund of the Energy and Resources Group, the Hewlett Foundation, and the Bullard Fund for Forest Research.

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