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SUSTAINABILITY: A plural, multi-dimensional approach

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Abstract

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Sustainability, along with productivity and equity, can be thought of as the umbrella concepts that cover most societal concerns. Although routinely used as synonymous with all environmental concerns, the concept of sustainability is more useful if restricted to concerns about the maintenance of well-being over time. A structured approach to discussing such a formulation of sustainability is presented. It begins with the normative questions of "Sustain what?" and "Over what time scale?". Typical attempts to come up with unique global answers to these questions are described, and their limitations and dangers exposed. The question "What?" is shown to be inextricably linked with the questions "For whom? By whom?". It is argued that abandoning a search for GNP-like indicators of aggregate sustainability, and embracing the plural nature of sustainability objectives is imperative. It is shown that sustainability analysis can proceed more fruitfully by focussing on what qualities are required of a system to sustain the flow of single or multiple products in a fluctuating environment, and what the appropriate scales for analysis and action might be. Drawing upon ideas from ecology and systems theory, sustainability is conceptualized as encompassing the attributes of dynamic equilibrium, reliability, resilience, and adaptability. These attributes depend not only on internal characteristics but also on the nature of connections with other systems, as is illustrated with the example of trade. Questions of scale and scope of analysis and action are examined, and ways of overcoming the commonly expressed difficulties are suggested.

SUSTAINABILITY: A plural, multi-dimensional approach

1 Introduction

There comes a moment of truth in the life of every concept, when it either acquires structure and meaning, or joins the smorgasbord of hopelessly vague and all-encompassing phrases. The concept of "sustainability" is, I believe, approaching such a moment. Originating as the narrow and (apparently) well-defined concept of "sustained yield" in renewable resource management, the concept has been expanded in the course of the past decade or so to include all socio-environmental issues, and has become an integral part of the captivating Sustainable Development rhetoric. On the other hand, most reviewers of the booming sustainability literature express sentiments to the effect that "on a substantive level, no consensus has been reached with regard to the meaning and applications of the concept", and furthermore, they refrain from proposing "an alternative model of sustainability [because] such an exercise is bound to fail when dealing with what is in fact a value-laden concept" (Dixon and Fallon, 1989, emphasis added).[1]

Should one then conclude that sustainability is a lost cause, a phrase that means everything to everybody but nothing to the analytically minded? I believe that, while using the concept involves many value judgements and analytical complications, it is both possible and necessary to provide it with more structure and meaning. Possible, because even "poverty" and "justice" are value-loaded and analytically slippery, but nevertheless useful, concepts. And necessary, because alternatives such as "conservation" or "environmental soundness" are worse. Moreover, the use and abuse of sustainability as a guiding principle for analysis and action is here to stay. Indeed, at a recent conference on sustainability, I watched in some alarm as virtually all the scientists present

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[1] Other reviews of sustainability include Brown (1987), Lélé (1988), Cocklin (1989), and Pezzey (1989a; 1992). For a review and deconstruction of the Sustainable Development rhetoric, see Lélé (1991).

concurred with the following bold call:

> What we need is the ecological equivalent of the Gross National Product. ... It will have to reflect a measure of the net primary productivity, the biological diversity and perhaps other factors integrated over a mosaic of different ecosystems..... A sustainability index could be the fulcrum we need to move the world toward a safer future (De Souza, 1992).

Clearly, Dixon and Fallon's misgivings are not universally shared!

This paper is not meant to be another literature review, nor a discussion of how to make the transition towards a particular vision of a sustainable society. It focusses on examining the nature and role of value judgements in sustainability thinking, and the scope for and limits of scientific analysis. It seeks to expose the fallacies in and dangers of ignoring the former, while attempting to contribute to the latter, and exploring the interplay between the two. The paper is organized in three parts. Part I (sections **Error! Reference source not found.-Error! Reference source not found.**) contains a brief definition of terms, a discussion of when "environmental issues" might or might not be primarily "sustainability issues", and identifying the set of questions that any discussion on sustainability must address. In part II (sections **Error! Reference source not found.**-0), I examine the value-laden questions from this set, critique the manner in which they are being answered, and argue for a more plural and socially-sensitive approach to sustainability analysis. With this perspective, I take up the more analytical questions in part III (sections **Error! Reference source not found.**-0), wherein I attempt to provide an over-arching framework, using insights from ecology and systems theory, and illustrate its usefulness with a specific example. Issues of scope and scale of analysis, which have bothered sustainability analysts for long, are also discussed.

PART I: BASIC DEFINITIONS, CONCEPTS AND QUESTIONS

2 Premises and Terminology

To avoid the confusion that characterizes much of the sustainability debate, I shall outline briefly my assumptions (and therefore my audience!) and terminology (and therefore my conceptual and normative biases).

2.1 Premises

To discuss the concept of sustainability is to admit the existence of certain limits: some "ultimate" environmental limits to resource availability, and pollution assimilation capacities, and limits to our ability to foresee the future and to always behave individually and collectively so as to further declared social goals. This paper is therefore addressed to those who accept that current and future human misery needs to be avoided or reduced, that some changes in the current pattern of human use and abuse of the natural environment are necessary to achieve such reductions, and that these changes will have to come about by some combination of changes in values, institutions, and technologies.

2.2 Terminology

I categorize all desirable societal goals and aspirations in terms of three "meta-objectives", that humans demand of any activity, viz., productivity, sustainability, and equity.

(1) Productivity is the ability of any socio-environmental system to provide current human well-being, which in general consists of material and spiritual elements.

(2) Sustainability is the ability of the system to be productive for some time into the future. That is, sustainability encompasses all elements related to the distribution of productivity across time.

(3) Equity is the ability of the system to distribute productivity in a fair and equitable manner, and includes elements of process and condition. That is, equity encompasses all concerns related to the distribution of productivity across currently living beings.

Assuming further that material well-being has a strong ecological basis (such as agricultural production or clean air) and spiritual well-being has a strong social basis (such as peace or a sense of community), I distinguish between "ecological" (or environmental or biophysical) sustainability, i.e., <u>the maintenance of the ecological basis of productivity</u> and social (or cultural) sustainability, i.e., <u>the maintenance of the socio-cultural basis of productivity</u>.

One could of course argue that "maintaining productivity in time" or "distributing it fairly within the current generation" is itself part of "human well-being" broadly defined (or, in the language of economics, the inter-temporal and inter-personal distributions of utility are included in the aggregate utility function). However, I believe that the above separation is useful because it corresponds to existing "clusters" of ethical concerns and priorities in the environment-development debate, viz., concerns about (a) one's own well-being, (b) future well-being of one's progeny or the human species at large, and (c) intra-generational distributive issues, including the well-being of other living beings. These clusters would be overlapping but not congruent in terms of their objectives and their operational requirements (see Fig. 1).

[Figure 1 here: THREE OVERLAPPING CIRCLES]

3 Are all environmental issues = sustainability issues?

Many current human activities are likely to have delayed negative impacts on the actors themselves or their descendants. Renewable resources are classic examples: over-harvesting now leads to reduced yields in the future. These problems can be said to lie in region A in Figure 1. They arise out of the nature of ecological processes to produced delayed feedbacks, and can be called "temporal externalities". In other cases, such as exhaustion of non-renewable resources or loss of genetic potential, the future impacts may be spread over a larger community. But the time-delay is at least partly responsible for the presence of the problem.

Consider, however, a factory releasing pollutants into a river and so affecting the health of people downstream. This problem, a "spatial externality", reduces the well-being of other humans right now, without necessarily reducing the well-being of the polluter in the future, i.e., it lies in region B in Figure 1. It arises out of the nature of ecological processes (often aggravated by modern technology) to transport or disperse effects. It exists usually because of the asymmetry of political and economic power between the polluter and the pollutee, and it needs to be recognized and dealt with as such, i.e., as a problem of intra-generational equity. Recognition of the fact that all environmental problems are not necessarily problems of (un)sustainability would go a long way towards reducing confusion about and abuse of the concept of sustainability.

To the extent that ecological processes tend to disperse the impact of an action in time and space, one might argue that the temporal aspects of material well-being are inextricably linked with the spatial ones. That is, most environmental problems might lie at the intersection of regions A and B in Figure 1. They therefore need to be addressed from both sustainability and equity perspectives. Nevertheless, the distinction is useful, as it corresponds to the different clusters of concerns described in the previous section, to different attributes that one might desire in a vision of a future society, and different sets of ecological and socio-economic factors that create the environmental problems, thus providing analytical clarity.

4 Fundamental questions in sustainability

Any systematic discussion of the concept of sustainability has to address the following questions:

(1) WHAT is to be sustained? A particular resource at a particular stock level? A particular ecosystem in a particular form? Employment ? Income? Or aggregate utility?

(2) For HOW LONG is it to be sustained ?

(3) HOW does any system sustain the desired objective over time? That is, what general attributes

typify a sustainable system?

(4) On what spatial and temporal SCALE is it appropriate to apply the criteria for sustainability? How does one deal conceptually with trans-boundary effects?

(5) What CAUSES unsustainability to occur? And therefore how can one move the world towards a more sustainable society, however defined?

Answering questions 1 and 2 appears to involve many value judgements, while questions 3, 4, and 5 appear to be largely analytical in nature. In the next part of the paper, I shall focus on questions 1 and 2, and shall explore questions 3 and 4 in part III. While answering question 5 is beyond the scope of this paper, systematization of our thinking about questions 1-4 should benefit future enquiry into it.

PART II: VALUE JUDGEMENTS AND THE MYTH OF OBJECTIVE AGGREGATE INDICES

5 What is to be sustained ?

At one level, the answer could be unanimous: "the well-being of all current and future living beings", and hence "the productivity of all socio-environmental systems". Operational answers, however, vary substantially, as they involve making different assumptions about what constitutes human well-being, and about the validity and feasibility of aggregating these constituents across space and time. I have arranged the four typical answers in a hierarchical manner in Table 1, in decreasing order of the number of underlying assumptions. I shall discuss them in that sequence, examining the assumptions made in each case.

[Table 1 here]

5.1 Non-decreasing Aggregate Utility

Answer (1), i.e., maintaining aggregate utility non-diminishing for all time is the neo-classical economists' definition of sustainability (Pezzey, 1989b). Its apparent simplicity is attractive, as only one constraint is added to the problem of "maximizing the discounted present value of [aggregate utility]". This basic formulation of welfare economics is, however, plagued with major problems, viz., that estimation of utility and aggregation across individuals (and nations) is impossible without some logically indefensible assumptions about interpersonal utility comparisons, and some value judgements about the relative weights assigned to individual preferences (Bromley, 1990). To these grave difficulties is now added the need to estimate individual preferences across all future generations! In other words, this approach has "the overwhelming disadvantage .. that it defines one imprecise concept (sustainability) in terms of something … even less definable [utility]" (Daly, 1991).

5.2 Non-decreasing Natural and Human Capital

Answers (2) and (3) avoid the problem of estimating and aggregating the elusive utility functions by explicating a particular view of what provides current and future productivity, viz., the quality and quantity of stocks of natural and man-made resources and assets. Of these, answer (2) imposes a weaker requirement: only the sum total of natural and man-made capital needs to be maintained constant. It is argued that, historically, exploitation of natural resources has led to the creation of manufactured physical assets (roads, houses, machines) and human assets (individual skills and technical know-how). Therefore, ensuring future productivity does not demand "the preservation of the current stock of natural resources or any particular mix of human, physical, and natural assets" (Repetto, 1986 p.16).

To say that such exploitation and transformation can continue indefinitely without diminishing productivity is to assume that (a) these "manufactured physical assets" can continuously substitute for land and other exhaustible resources (including environmental assimilation capacities), and (b) knowledge (through technological progress) can forever ensure a non-decreasing level of consumption from finite resources and capacities. The flaw in assumption (a) has been exposed by Daly (1991). For instance, artificial fertilizers can compensate somewhat for the shortage of cultivable land, but can never eliminate the need for it. In general, man-made capital is a complement to natural resources, not a substitute for it.

Assumption (b) essentially implies that there is no minimum physical resource (or pollution) content per unit of output value (an assumption nonchalantly embraced by neo-classical economists; see, e.g., Dasgupta and Heal, 1979, p.207, or Baumol, 1986). As intuition suggests, this assumption, when applied to mineral extraction, violates the second law of thermodynamics (Lozada, 1992). Further, limits on assimilation capacities may be reached much before we run into resource availability limits (e.g., Holdren and Herrera, 1971, p.140; Ehrlich *et al.*, 1977, p.536). Finally, even if one were to accept uncertainties about the latter, or about the time before we reach the former, proceeding as if such limits do exist is clearly the more sensible strategy to adopt (Costanza, 1989).

5.3 Non-decreasing Natural Capital

Recognizing the ultimate non-substitutability between natural and man-made capital, Pearce (1988) and others (e.g., Costanza and Daly, 1991) argue for maintaining the stocks of each kind of capital intact or non-decreasing. Given the "environmentalist" roots of the debate, the focus has been on Natural Capital (NC), which is 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, p.6).

NC, as a pedagogical construct, is useful in conveying the notion of sustainability as analogous to not running down one's bank account. If, however, it is to be used in policy formulation, one has to decide between requiring constancy of aggregate NC and requiring constancy of each component of NC; I call these the "aggregative" and "non-aggregative" versions of NC respectively, and they correspond to answers 3(a) and 3(b) in Table 1.

Limitations of the "constant NC" criterion

Regardless of which version of NC is used, there are two major limitations to the idea that non-diminishing stocks of natural resources can ensure non-diminishing flows of material goods and services.[2] Firstly, these flows may not always monotonically increasing functions of the stocks. The growth of animal populations often resembles a logistic curve; a reduction in their stock level to below carrying capacity would, down to a point, increase productivity. If reductions (increases) in stocks lead to increases (decreases) in resource productivity, monitoring the stock will give misleading signals about sustainability. Therefore, a constant stock requirement may not be appropriate in many cases.

Secondly, notwithstanding assertions that higher NC provides for greater resilience (Pearce, 1988), "constancy of resource stock" is a fundamentally static criterion. It may ensure constant flows of products and services under "average" conditions, but cannot by itself ensure a system's resilience to the fluctuations, shocks and shifts of an uncertain and variable world. For a system to continue to be operational and productive in such a world requires specific kinds of internal structures and external connections, aspects that I shall elaborate on later (section **Error! Reference source not found.**).

Aggregate Natural Capital as the Sustainability Index

Most of the proponents of NC, in fact, use the aggregative version, because they advocate (a) modifying the Systems of National Accounts to reflect changes in NC (e.g., Harrison, 1989), and/or (b) taxing activities in proportion to their depletion of NC (Costanza and Daly, 1992), and/or (c) using NC as a global sustainability index that will help determine whether or not we are on the path towards sustainability (see quote from De Souza in section 1). Each of these policy

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[2] I ignore here the obvious contradiction between using non-renewable energy resources and wanting to maintain their stock non-decreasing, as it has been suggested that these resources could be used to make a transition to renewables (El Sarafy, 1989).

applications requires the measurement, economic valuation and aggregation (or comparison) of the diverse components of NC, including biological resources, material resources, assimilative capacities, and ecosystem services. But such aggregation is open to essentially the same criticism that applies to the aggregation of utility functions, viz., that it involves making value judgements about the relative weights to be assigned to the preferences of different users for the different components of NC. Thus, to insist that one can create a scientific indicator of aggregate sustainability is akin to insisting that one can use GNP as a scientific indicator of current human well-being.

On the other hand, the non-aggregative version of NC does not seem to have much practical use, because it cannot tell us whether "on the whole" the ecological basis for human well-being is deteriorating or not. Sustainability analysts therefore appear to be caught in a bind: they must either abandon all hope of informing policy (because they cannot decide which is the "more sustainable" policy option), or must perforce be unscientific!

6 The Ideology of Global Sustainability

There would not be much cause for alarm if this sense of "paralysis" were indeed being expressed in the sustainability discourse. In fact, however, the situation is quite the opposite. Attempts to define and choose criteria and indices for global sustainability began back in 1987 (Liverman *et al.*, 1988), and, with the adoption of the sustainability rhetoric by the World Bank and other major funding agencies, such attempts have proliferated and are beginning to define the sustainability agenda.

The situation bears a remarkable resemblance to that in conventional economic policy analysis, where the ideology of "economic efficiency" has ruled the roost (Bromley, 1990; also see Blaug, 1980). Just as most neo-classical economists insist that the choice of "Pareto optimality" as the decision rule and the use of "consumer and producer surplus" as a measure of social welfare are "scientific" and "objective" choices, today's global sustainability analysts appear to believe that the use of aggregate (GNP-like) indicators is quite "scientific". Just as economists disagree on details of the estimation of demand and supply curves, the global sustainability analysts may disagree on how best to incorporate NC into the system of national accounts. The bolder ones make stronger assumptions about the limits to substitution and technical progress, and so use "total NC" instead of aggregate utility or total capital as the sustainability objective, while still believing the essential objectivity of such constructs.

On the other hand, sustainability analysts trained primarily in the natural sciences may come up with a "physical" index, like the combination of global Net Primary Productivity and biodiversity suggested in the sustainability conference mentioned earlier (section 1). However, most natural scientists worry that, given limited knowledge of extremely complex and diverse ecosystems, single indices might be inaccurate or overly simplistic, and hence they adopt multiple indicators "for the time being". Such worries are certainly legitimate. But it is noteworthy that the fundamental flaw in such global indices (and also a limitation of each of its components), viz., that they also involve making many value judgements, does not appear to be widely acknowledged.

A classic illustration of how such pseudo-scientific thinking about sustainability leads to biased (and analytically incorrect) results is the "environmental sustainability ranking" presented by Goodland *et al.* (1990, Table II). They ranked different forms of utilization of tropical moist forests as follows:

Intact forests > Utilization of natural forest > Tree plantation > Agri-silviculture > Agriculture,

where ">" means "more environmentally sustainable". This ranking appears to be based on their definition of sustainable use as "the use of natural forest ... [that] indefinitely maintain[s] .. biological quality [and environmental services] unimpaired".

Two points need to be made here. Firstly, the products of the system chosen as objectives to be sustained are "biological quality and environmental services". But is the choice of these properties not a value-judgement? Would not a rubber tapper or a peasant cultivating a small patch of paddy in these lands have different (and possibly conflicting) objectives?

Secondly, the authors do not make a clear distinction between a productivity ranking, i.e., which land-use is more desirable in terms of the current magnitudes of the desired products, and a sustainability ranking, i.e., which land-use would be more likely to maintain these current magnitudes (whatever they may be) undiminished longer than others. That an intact forest will provide higher initial biological quality than any of the other forms of utilization follows by definition. On the other hand, that the biological quality of and environmental services provided by an intact forest will be maintained longer than those provided by a utilized natural forest or even agri-silvicultural system has not been demonstrated for moist tropical forests in general, and the authors do not provide any scientific justification for the ranking in any specific case either.

7 The Time Horizon

Choosing the time horizon over which one wishes a particular benefit or component of well-being to be maintained is the second question primarily involving value judgements. Surprisingly, there appears to be little debate or disagreement here. A consensus seems to have been reached that (a) concern for sustainability is equivalent to concern for the "long term" (i.e., many, possibly infinitely many, generations; see WCED, 1987), and (b) the operational differences between different choices within this general range are negligible, i.e., given the uncertainties about the future and how we can affect it, a choice of 2 generations as one's time frame is to be operationally different from a choice of 10 or 20 generations.

A number of points, however, need to be made in this context.

(1) The Brundtland Commissions's definition of sustainability (maintaining the "ability of future generations to meet their own needs", WCED, 1987, p.43) makes the value judgement that future generations matter. Our particular definition of sustainability (maintaining welfare over whatever time horizon one chooses) implies that one could be "purely" selfish and yet concerned about

sustainability. I submit that the latter definition is more useful, as it includes those who are concerned about the possible decrease in their own well-being within their lifetime due to (say) climate change. In other words, concern for sustainability should not be reduced to a concern for inter-generational equity.

(2) A large portion of the sustainability literature has been devoted to whether higher discount rates reduce sustainability by providing incentives for short-term returns at the expense of long-term (usually environmental) costs, or whether they increase sustainability by increasing the premium on capital-intensive and usually environmentally destructive projects (see Pezzey, 1992 for a review). Norgaard and Howarth have, however, pinpointed the fundamental problem with this approach: the discount rate cannot be used as a tool to decide what the extent of our dowry to future generations should be; we have to make the decision about what dowry to provide first, and the appropriate discount rate will follow (Howarth and Norgaard, 1990; Norgaard and Howarth, 1991). The correct analytical question therefore is to what extent do people want to provide a dowry to future generations.

(3) Information is needed on a number of aspects of people's preferences with respect to the future. These include the nature of people's "impatience" and the appropriateness of a single discount rate, their willingness to tradeoff current benefits for their children's benefits, and, perhaps most neglected, their attitudes towards risky decisions about an inherently unknowable future.

(4) There has also been an undue emphasis on the (involuntary) short-term thinking of the poor (e.g., Dixon and Fallon, 1989, p.81), and not enough on the fact that the rich can be equally short-sighted (and voluntarily so), especially when capital mobility enables them to move on as resources get exhausted or degraded (e.g., Agarwal, 1985).

(5) Finally, it should not be assumed that all environmental problems are a result of short time horizons; as pointed out in section **Error! Reference source not found.**, many are a direct

consequence of intra-generational inequities in the power to enforce existing rights.

Once again, one notices an attempt to collapse complex and differing value judgements about how much one cares for one's own progeny and the future of mankind at large into a single index: the social discount rate. Too much attention is then focussed on how best to estimate this index, and not enough on what people's preferences really are, what different aspects they may include, and how they arise or vary in time and space.

8 A Plural and Socially-sensitive Approach to Sustainability

It seems that answering the first two basic sustainability questions, viz., "Sustain what?" and "How long?", requires answering a number of sub-questions:

(A) What are the different components of human well-being today and what will they be in the future? What should their relative ranking be? How should sustainability be ranked vis-a-vis productivity and equity? How far into the future does one's concern extend? If the answers to the questions in (B) below are unclear, how cautious should one be in transforming today's environment? And how should different answers to all these questions be translated into a collective choice?

(B) What environmental resources and social institutions provide the different possible components of well-being? What limits do environmental laws and socio-psychological "laws" impose on our ability to continuously obtain current or higher levels of well-being? To what extent is technological "progress" likely to expand these limits?

Clearly, questions in (A) require making value judgements. These judgements may be informed by the answers to (B), which are supposedly based upon objective scientific analysis and judgements. But the objectivity of the latter needs to be placed in perspective. Firstly, there is much room for "objective" disagreement around the scientific questions in (B): witness the raging debate on the likelihood of climate change. Secondly, even so-called "scientific" analyses and judgements are shaped in a social context. In the natural sciences, this context might manifest itself in the topics on which research occurs (e.g., pristine ecosystems) or does not occur (e.g., disturbed ecosystems). When natural scientists become activists, it shows up in the issues they champion, and in their often highly mechanistic world-views. The world-views and biases of social scientists show up in their choice of policy instruments (e.g., fiscal, regulatory and perhaps educational measures driven by the view that market-based or managerial measures work best). Finally, it must be recognized the political process of translating individual answers to (A) into collective choices occurs in a world with highly unequal distributions of the opportunity and power to influence this process. Certain preferences may never get articulated, while others are presented as representing a consensus.[3]

In other words, sustainability is fundamentally a social construct (Berger and Luckmann, 1966), and any attempt to operationalize it must be fully sensitive to not only the difference between scientific analysis and value judgement, but also the social context in which the analysis is performed and implemented. The questions "Sustain what?" and "For how long?" cannot be answered in the abstract without reference to the questions "For whom?", "By whom?" and "How?". That is, whose definitions of well-being, choice of time-horizon, and ethics are being used? Who decides, and through what socio-political process? Who implements, and in what manner?

How then does one conduct "objective" policy analysis in the absence of an objective sustainability index? Bromley (1990) provides an answer in his analogous appeal for abandoning the ideology of economic efficiency:

> A reasonable place to start is with a simple word--"analysis"…To analyze something is not to reduce all of its components to dollar estimates 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, and what this means for the full array of beneficial and harmful effects.

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[3] See Thrupp (1990) for an elaboration and critique of many such biases in the Sustainable Development movement.

Sustainability analysts must similarly embrace the plurality in human values and their rankings, and in perceptions about the environment, technology and social processes. For instance, in analyzing the sustainability of a particular moist tropical forest, the analyst should attempt to
(1) understand the social context of the forest; e.g., who are the different beneficiaries, what is their socio-economic status;
(2) identify the typical set of products and services provided by the forest (say fuelwood, timber, and biodiversity) and the beneficiaries associated with each (local villagers, urban consumers, and the global community, respectively);
(3) ascertain the personal preferences of these beneficiaries, with respect to the products and with respect to time, risk, etc.;
(4) determine the outcome of different management options in terms of the magnitude (i.e., productivity), distribution (i.e., equity) and temporal variation (i.e., sustainability) of the different products, and possible tradeoffs and overlaps. For example, is it more economical to manage the forests for timber than for fuelwood? Are the timber benefits less equitably distributed than those from fuelwood production? To what extent is either production compatible with maintaining biodiversity?
(5) keeping in mind that "means" matter as much as "ends", re-examine the "management" options in terms of their procedural content, i.e., to what extent will they involve and strengthen the capacities of the people closest to the resource and the people most in need?

Such an analysis would require the elaboration of the broad concepts of productivity, equity and sustainability into analytically useful categories, components and relationships. While the first two concepts have long pedigrees, sustainability is a much more recent and, as I have shown, a poorly articulated construct. I shall attempt an elaboration of this construct in the next part of the paper.

PART III: AN ANALYTICAL FRAMEWORK

I defined sustainability as the ability of any system or activity to continue to be productive through an variable and uncertain future. I also argued that the plurality of the choice and ranking of multiple products by multiple user communities must be incorporated into our analyses. We now come to the third and fourth questions outlined in the basic framework (section **Error! Reference source not found.**), viz., what are the general attributes of a sustainable system, and how does one determine the scale and scope of the analysis?[4]

9 Attributes of a sustainable system

As mentioned earlier, while most sustainability thinking has been in terms of constancy of resource stocks, other dynamic attributes need to be incorporated to make the concept applicable in a non-constant world. With this in view, I argue that sustainability is best conceptualized as consisting of four gross attributes[5]:

(a) dynamic steady-state,

(b) reliability,

(c) resilience, and

(d) adaptability.

Below, the motivation for introducing each gross attribute, its likely components and limitations, and possible general prescriptions for enhancing that attribute are described.

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[4] I must emphasize that the discussion is limited to when one might call any system sustainable or unsustainable, and is based upon a systems theory perspective; a discussion of the complex array of social conditions that cause ecological or social unsustainability is beyond the scope of this paper.

[5] This conceptualization was briefly presented in Lélé (1988); see also Conway (1984) and Charoenwatana (1988).

9.1 Dynamic Equilibrium

While "non-diminishing" does not necessarily mean constant, constancy in time or equilibrium has always been the intuitive idea underlying sustainability (see Figure 2). In simple stock-flow models of dynamic chemical or biological systems, one can conceive of a dynamic equilibrium, resulting from a balance between growth and harvest, birth and death, or pollutant inflow and dispersal.[6] The analytical questions in this context are: (a) What are the indicators and recipes the model prescribes? (b) How well does the model work for real-world biogeochemical or biological systems? (c) How does one analyze static systems?

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[6] In some cases, the prescription may not be of equilibrium, but rather of limits, or cutoffs, such as an upper limit to pollutant loads in drinking water supplies. Such a cutoff can, however, be thought of as the combination of a target average equilibrium level and a limit on its variability.

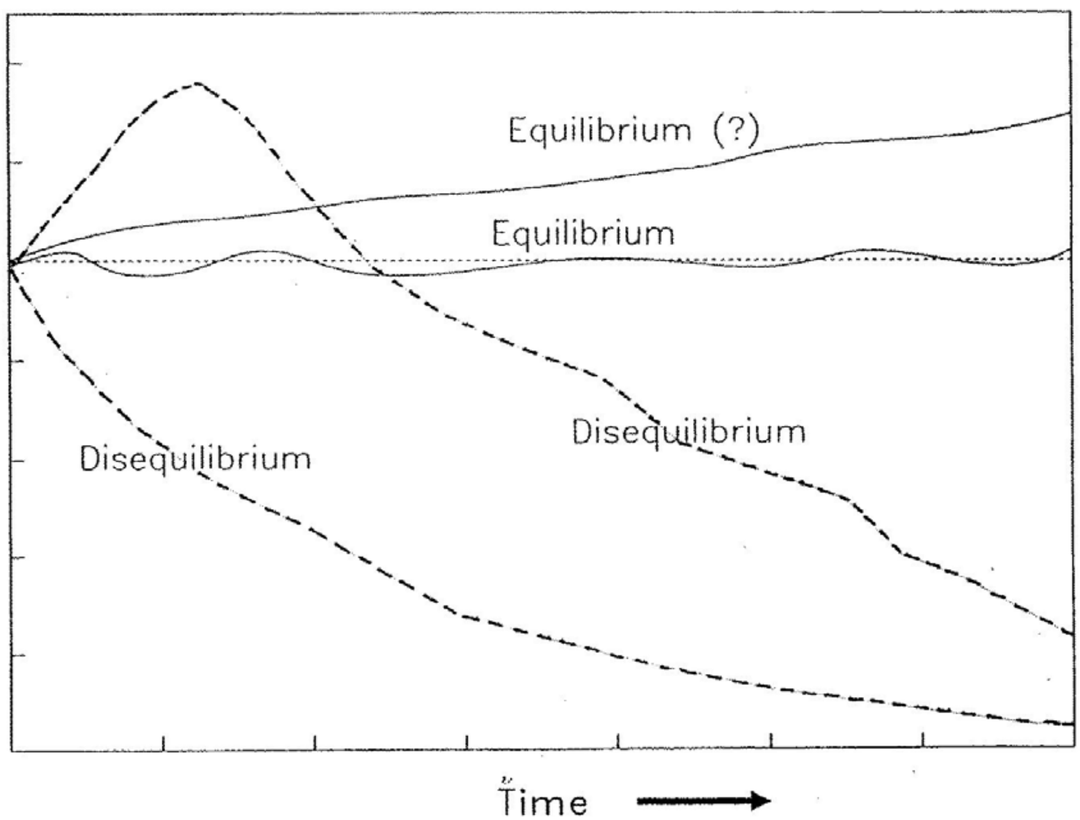

FIGURE 2. **DYNAMIC EQUILIBRIUM**

In a simple inflow-stock-outflow model, a constant stock implies balance, and a growing or decreasing stock implies imbalance. Thus, falling stock size is thought of as an indicator of unsustainability in use, and reducing outflows (harvest) and increasing inflows (production) as the recipes for chemical (biological) resources yielding positive benefits; the opposite applies for pollutants. This basic model has almost completely dominated thinking about sustainability to date.

There are, however, a number of problems in applying this model, some practical and some conceptual (see Lélé, in preparation, for details). Firstly, as mentioned earlier, stock size may be a misleading indicator of equilibrium in a resource with a logistic function. Secondly, in complex non-linear ecosystems, and/or ecosystems producing multiple outputs with inter-dependent growth rates (such as tropical forests used for fuelwood, fodder and timber), there may be multiple equilibria ("alternative stable states": Holling, 1986), or none at all. Thirdly, the diagnosis that "unsustainable use occurs when extraction exceeds production and eats into resource capital, thus reducing future production" may not apply. For instance, in annual grasslands or annual crops, the aboveground biomass production and consumption are guaranteed to be equal, because there is no aboveground biomass stock that grazing or harvesting can directly cut into. Finally, external conditions and internal system structure may be changing so rapidly that the idea of equilibrium may appear to be no more than a chimera.

Consequently, in all ecosystems, "qualitative" aspects of the manner of resource harvest and protection, such as the frequency, timing and method of extraction, may be as or more important for maintaining equilibrium than "quantitative" aspects such as the amount extracted (see, e.g., Franklin, 1992; Lélé, in preparation). For indicators, other state variables that better reflect long-term productive potential, such as soil fertility in agriculture (Parikh, 1989), will have to be identified. And the criteria may have to be in terms of limits beyond which the system shifts into new modes of behaviour, not single target values.

Equilibrium with respect to biodiversity is difficult to conceptualize, since it is not clear whether one wishes to maintain just the diversity, the actual species composition or the whole ecosystem intact (see Rochlin and Jensen, 1990). Conceptualizing equilibrium for mineral resources, where there is no growth or destruction of the resource, is even harder, and it seems impossible for non-renewable energy sources, where available energy is consumed, but never created. The only way to apply the equilibrium criterion to the latter contexts is in the inputs into and impacts of their extraction and use, phenomena that would normally appear to be "external" to the analysis. The same problem of external impacts and inputs occurs even in the case of renewable resources: nutrients removed through extraction may have to be compensated externally, and the management and protection "inputs" are always external. These questions of scale and scope of analysis will be discussed later.

In the context of social sustainability, while a similar notion of balanced inflow and outflow (e.g., balanced budgets, or balanced flow of information: Rambo and Sajise, 1984), the complexity and rapid evolution in these systems (and the inexhaustibility of products such as information) suggests that its practical application would be both difficult and limited.

9.2 Reliability

A fundamental difficulty with the notion of dynamic equilibrium is the constantly changing environment. As a first approximation, one tends to deal with averages over time, assuming the system to be in steady-state if the average value of some property remains unchanged (within certain tolerances) over a certain period. But averages are not enough, as population biologists know: larger fluctuations around the same average population level increase the extinction probability, and a population once extinct cannot be revived. Social scientists realized the importance of variability when they tried to understand the reluctance of farmers to cultivate high-yielding but low-reliability crop varieties. Given the variability in environmental and social conditions, ranging from year-to-year climatic fluctuations to decade-long business cycles, a sustainable system must have the attribute of "reliability": the ability to achieve the desired level with a certain minimum probability[7] (see Figure 3).

Are there any general strategies for enhancing reliability? Again, recipes fall into two general categories: those based on modifications in internal components and structure, and on control of external sources of variability. In general, they may include increasing reliability of individual components, adding of redundant components (but see Hudson, 1981 for the unreliability of redundancy!), increasing storage of inputs or outputs, diversification of products or activities, or movement away from variable environments (migration).

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[7] This definition of reliability resembles certain definitions of "inertia" (Westman, 1986), or "short-term homeostasis" (Conway, 1984).

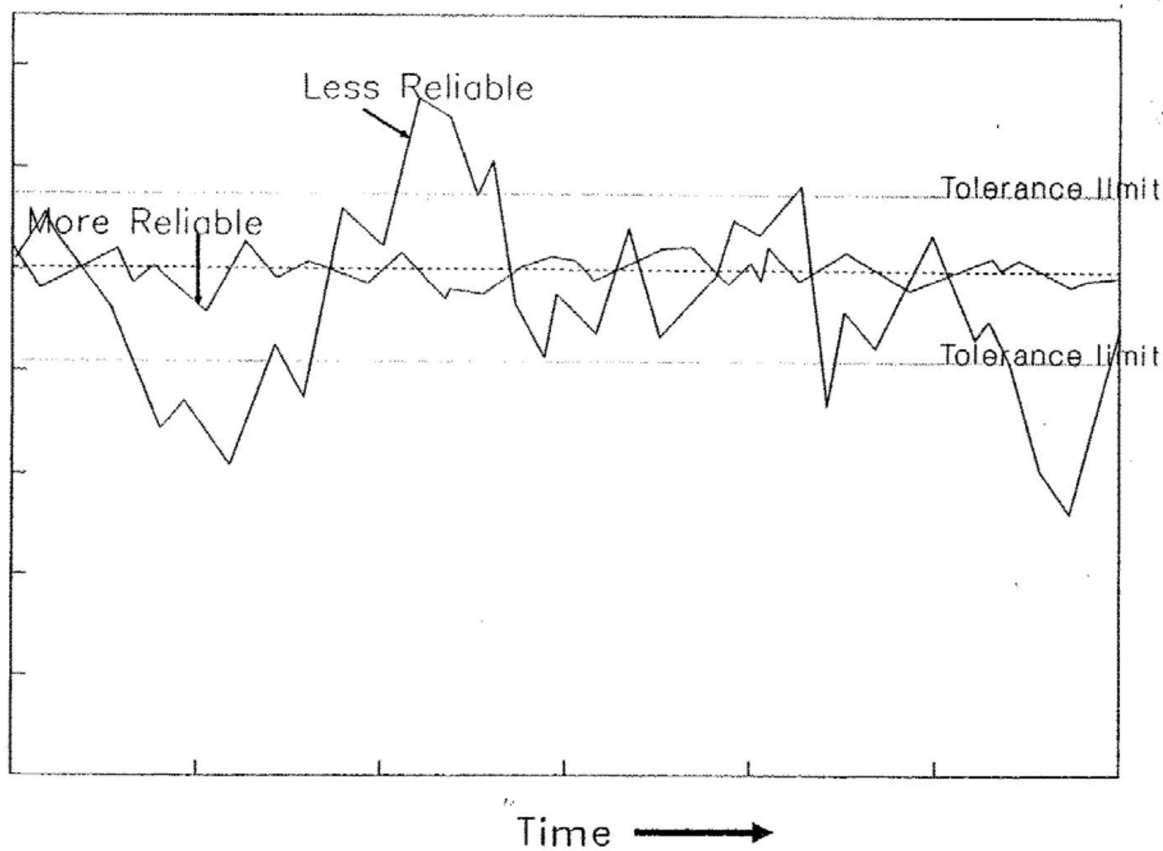

FIGURE 3. **RELIABILITY**

9.3 Resilience

Reliability, however,"does not imply … the ability of a system to accommodate surprise and to survive … under unanticipated perturbation" (Fiering, 1982b, see also; Fiering, 1982a). Indeed, in some systems such as semi-arid grasslands, the variation in environmental conditions may be so high and unpredictable as to make the notions of equilibrium and reliability meaningless. Catastrophes (such as droughts) are bound to happen; what is needed is the ability to recover rapidly when environmental conditions become favourable, i.e., the attribute of resilience.

A more comprehensive definition of resilience would be that it "refer[s] to the pace, manner, and degree of recovery of ecosystem properties" following major stress (Westman, 1986). Resilience would include at least five distinct components: (a) the extent of deviation under stress,

(b) the rapidity of restoration of an equilibrium following disturbance, (c) the magnitude of stress beyond which return to the original state no longer occurs, (d) the degree to which the path of change under stress differs from the path of recovery upon removal of the stress, and (e) the difference between the pre-stress and post-recovery equilibria. It is also useful to distinguish between "acute" and "chronic" stress.

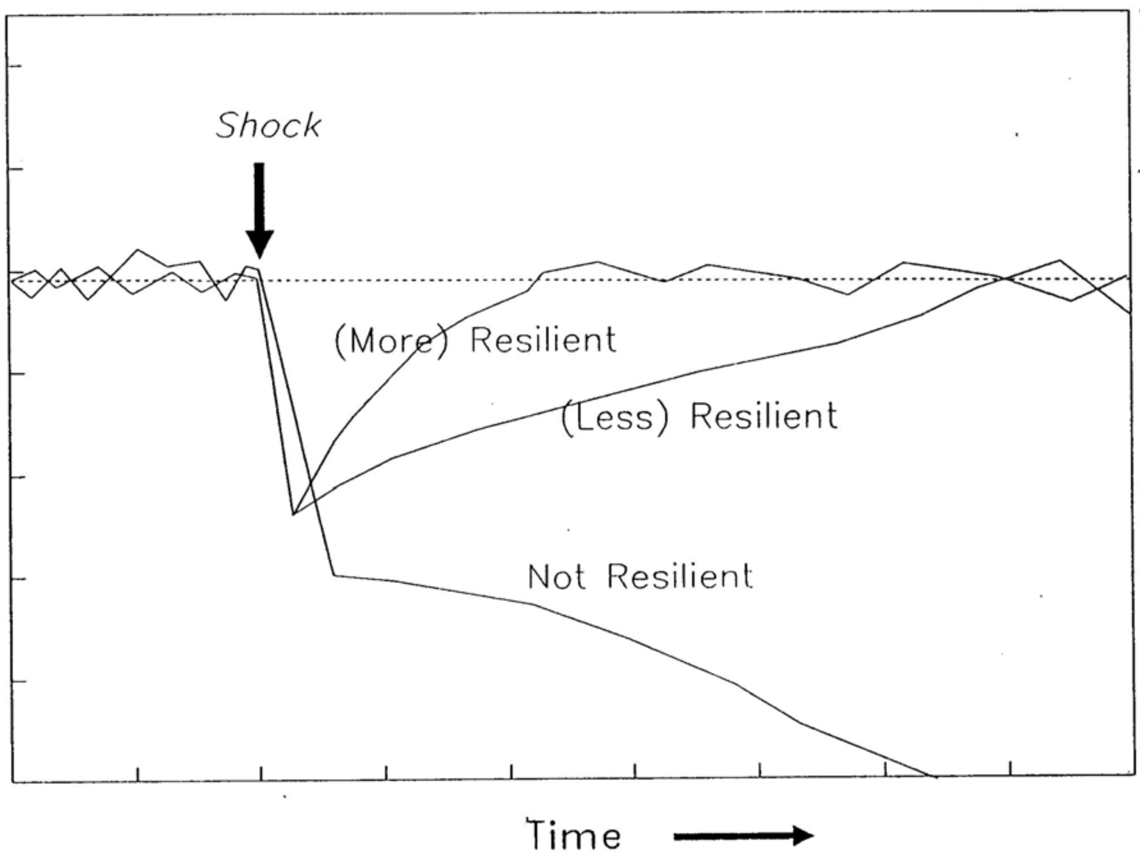

FIGURE 4. RESILIENCE

Are there general recipes for resilience? Many recipes may overlap with those for reliability. Others include risk-pooling across space (insurance) and across time (savings) or safety nets (family ties or state-managed welfare). Attempts are also being made to reduce the costs of disasters by developing advance warning systems, such as weather satellites or seismological monitoring.

9.4 Adaptability

In discussing reliability and resilience, for analytical convenience, we made the implicit assumption that long-term average conditions are constant. Environmental conditions (e.g., climate) may, however, exhibit definite shifts, either inherent (e.g., glaciation) or human-induced (e.g., the greenhouse effect). Human beings as a species have certainly demonstrated an innate ability to adapt to a large variety of environmental conditions on historical time-scales. But rapid technological innovation in the modern age has created hitherto unprecedented rates of socio-environmental change. To sustain well-being under these circumstances, we will need to cultivate actively the attribute of adaptability.

Adaptability too may have several components. One would be the internal capacity to detect and interpret "secular" trends in environmental conditions, and to modify behaviour accordingly, a capacity broadly denoted as "learning". The second component could be the retention of enough options to actually allow such a modification. Since taking actions that are irreversible effectively shuts off some options, such actions might be thought of as reducing adaptability. Conserving biodiversity is an obvious example of maintaining future options. Submerging large tracts under dams would be an example of irreversible land-use change, and hence of reductions in adaptability. Prevention or mitigation of change that may be too dislocating may be a third component of adaptability, especially if the change is a direct result of human activities, as in the case of the greenhouse effect.

As measures of the capacity to adapt, one could use the speed and cost of adjustment. Maintaining productive potential rather than a particular kind of productivity might ensure the existence of options in the case of some renewable resources (see, e.g., Svedin, 1988 and Franklin, 1992). Some other tentative recipes for adaptability are given in Table 2.

9.5 Summary of attributes

To summarize, the conceptualization of sustainability as consisting of the gross attributes of dynamic steady-state, reliability, resilience, and adaptability is an attempt to capture the essence of sustainability in a parsimonious manner (see Table 2). Given the complex nature of the dynamic attributes, other classifications will always be possible. But the essence would remain: to be able to provide benefits continuously over time, a system must have attributes that help it deal with the variability, uncertainty, and change that characterizes the real world.

[Table 2 here: Attributes of sustainability]

Two points may be noted in this context. Firstly, clarity as to the properties that provide the desired benefit is necessary. For instance, ecologists working on reliability and resilience use various indices of species composition as the "desired" property. These results may not apply if, e.g., the focus is on net primary production. Indeed, identifying situations where multiple objectives may be achieved with the same recipe or technique or social arrangement is one of the greatest challenges before socio-environmental analysts.

Secondly, whether applied to ecological aspects or socio-economic aspects of a socio-environmental system, the problem will always have two parts: intrinsic properties and structural properties and relations. The former relates to the dependence of sustainability attributes upon the intrinsic properties of the system, whether the pest-resistance of crops or fire-resistance of tree seedlings. The latter aspect deals with the structure of interactions between the system and its environment, including other systems. It therefore focuses on features such as connectance, hierarchy, and feedback. This distinction is analogous to the ecologists' distinction between autecology and synecology (Westman, 1986), and I shall take the liberty of using these terms for my purposes. In the next section, I shall provide a specific example of how this framework might provide new insights into the organization of economic activities.

9.6 An example: the synecology of Trade

In dynamical systems theory, Siljak has shown that "although increased complexity may promote [asymptotic] stability[8], it is only when complexity is limited that a large system can remain stable despite structural perturbations" (Siljak, 1978, p.xii). Or, "a dynamical system composed of interconnected subsystems is reliable if all subsystems are self-sufficient and their interdependence is properly limited" (*ibid.*, p.2). In a highly interconnected system therefore, small perturbations (such as local disruptions in structure, or minor changes in some exogenous or endogenous parameters) may result in wild fluctuations, i.e., unstable or volatile behaviour. Such behaviour has in fact been observed in large, interconnected power systems, sometimes leading to what is called "cascading blackout", wherein a minor problem at one location results in the tripping of an increasing number of safety devices and ultimately leads to power outages over large regions (Fink, 1991). Remarkably similar behaviour has been noticed in international stock markets as their interconnectedness has increased through rapid advances in (and unthinking application of) communications and computer technology (Rochlin, 1991).

Since economic activity in general and trade in particular can be conceived of as a large-scale system of transfer of goods from one node to another in the network of the world economy, these results may be readily applied to trade. A high degree of global connectance would correspond to a situation in which most nations eliminate barriers to free trade and maximize their "comparative advantage". The theoretical and anecdotal evidence outlined above suggests that such a situation may result in reduced system stability, which in practical terms means that exogenous fluctuations such as drought, shifts in consumer preference, or embargoes would result in major economic and social disruptions. If the structural and asymptotic stability of large-scale systems requires locally high but globally sparse connectance, this would call for limited global trade while retaining a fair

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[8] In dynamical systems theory, a system is said to be asymptotically stable if, when perturbed by a small amount away from equilibrium, it ultimately returns to equilibrium. It is said to be connectively stable if it shows asymptotically stable behaviour in spite of changes in the interconnections between its elements (Siljak, 1978; Casti, 1979). Stability, in this sense, is very similar to my definition of "resilience".

amount of regional trade, and large countries like India, Brazil and China might possibly form quasi-self-sufficient blocks.

Autecological considerations also suggest that portfolio diversification strategies are more prudent than pure "efficiency" calculations in an uncertain world, especially if a country is poor and hence risk-averse. Such strategies would include not only diversity in trading partners and diversity in goods traded, but also a balance of local and imported production. Thus, some form of "limited self-sufficiency" becomes an operational requirement deduced from the objective of sustainability, rather than a dogmatically pursued goal in itself.[9]

10 Scale, Scope and Trans-boundary effects

Sustainability analysts have grappled with the problem of specifying spatial boundaries or the scale of analysis. But, apart from stressing that "any study of sustainability must make ... time and space assumptions explicit" (Brown *et al.*, 1987), not much light has been cast on the issue. Part of the difficulty lies in the confusion of analytical issues with prescriptive ones. "Which state variables should be monitored, and on what spatial and temporal scale, so as to obtain information on the sustainability of the system?" is the basic analytical issue. As we shall see, this question appears to be inextricably linked to the following policy questions: "On what scale should attempts to achieve sustainability be made and coordinated? Given that ecological and socio-economic systems are both highly interlinked and hence prone to externalities, is it possible and desirable for a subset of the global community to aspire for or achieve sustainability? If so, will such local attempts conflict with sustainability at a higher spatial scale? Are there any rules that might avoid such conflicts?" In answering these questions, I shall also try to explain how the idea of self-sufficiency often gets mixed up with sustainability.

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[9] Stability is just one of the many arguments against the doctrine of unlimited free trade; Lélé (1991) gives an overview of the others.

10.1 "Natural" scales for analysis and action

Let us consider first the analytical question. While all scientific analysis requires choosing the variables to be included or the spatial scale of the analysis, most such choices are usually based upon intuition. Natural scientists have only recently begun a systematic examination of the question of scale, discovering in the process that natural phenomena occur at many "natural" spatial and temporal scales, with cross-scale linkages that are often crucial in determining the dynamics (see Levin, 1992 for a review). There is, however, no single "correct" scale, as the appropriateness of the scale depends not only on the observed phenomenon, but also on the particular management objective. But it might be possible to suggest some minimum bounds, both spatial (e.g., continental or global scale for atmospheric problems, regional or local for watershed problems, or local for solid wastes) and temporal (e.g., one growing season for annual crops, one rotation for forests).

"Natural" scales in social phenomena are even harder to pinpoint, except perhaps the temporal scale of generational change. Limits on the sizes of social organizations may have originally corresponded to "natural" geographical limits, but have now been transcended by modern communication technologies. While social scientists may be hard-pressed to identify the socially optimal scale of action and coordination, there are clear hints that current organizational scales may often be too large. Much of the rural development literature, for instance, is pointing to the high social costs (in terms of inefficiency as well as inequity) of centralized coordination and control in the modern nation state, and the need for "bottom-up" or "decentralized" approaches to planning and implementation of development projects (e.g., Chambers, 1983; Agarwal and Narain, 1989).

10.2 Does sustainability analysis require self-contained systems?

In [any] open exchange system … the ultimate level of analysis would need to be the global scale (Cocklin, 1989).

Openness creates the … problem of determining when sustainability is an inherent property of the defined system …, or when [it] is so dependent on external forces that the system level should be upgraded" (Lynam and Herdt, 1988).

No human-ecosystem is completely closed (even the globe is open to energy flows!). Any analytical scale smaller than the whole globe will have flows of materials, energy and information across it, either as "outside influences" or (to coin a phrase) "inside outfluences". These may be "purely" ecological flows (such as air, groundwater, or pests) or "socio-economic" flows (imports and exports of goods, services, money, labour, information). But does that make the global scale necessary in every case, as the quotes above suggest?

None of the attributes of sustainability outlined earlier require that the system be a closed one. They only require some estimates of the time-behaviour of those external variables that are likely to affect system productivity. Admittedly, in a world where everything appears to be connected to everything else, and particularly in environmental issues where problems have often arisen because some such connections have been ignored, deciding the scope and scale of the analysis is not easy. But to lament that one does not have the physicist's or chemist's luxury of closed or tightly controlled conditions is to refuse to take up the gauntlet of real-life analysis. Choosing intuitive boundaries, and then doing sensitivity analysis with changing boundaries and variables might be a way to begin; the work by landscape ecologists on scale and pattern can certainly help in this matter.

10.3 Is local self-sufficiency desirable for sustainability?

Of course, the more self-contained the system, the greater its analytical tractability as well as the control exerted by the user on system parameters. Further, as the lessons from rural development mentioned above indicate, local planning and control appear to be social conditions favouring project success, especially in areas of great economic and cultural diversity. Finally, there is the belief that many environmental problems would not occur if producers and consumers could directly experience the (current externalized) costs of their production and consumption. In light of these arguments, one can understand why local self-sufficiency is often considered necessary for (or even completely identified with) sustainability (e.g., Cocklin, 1989), if not advocated as a goal in itself (e.g., Riddell, 1981; Tolba, 1984). On the other hand, if no system is a closed one, and modernization is further integrating the world, is not local self-sufficiency just a dream?

It needs to be realized, however, that the call for self-sufficiency is not meant as a move towards completely closed sub-systems, but rather for a reduction in the current openness or high level of interconnectedness. As the application of systems theory insights to trade issues (section 0) shows, our framework provides a new and "rigorous" argument for limited self-sufficiency. The "self-sufficiency versus interdependency" debate thus needs to be recast as "What degree and kind of self-sufficiency and interconnectedness will lead to what level of productivity, sustainability and equity?".

10.4 "Inside outfluences" and Micro- versus macro-sustainability

> In this open-exchange system, there is some difficulty in identifying whether sustainability at the local level is not compromising the objective [at a larger scale] (Cocklin, 1989).

This fear that sustainability at one scale may imply its absence or reduction at another scale is what I call the problem of "micro- versus macro-sustainability" (see also Svedin, 1988; Seetisarn, 1988). In many cases, this problem may actually result from lack of clarity in terminology or conceptualization.[10] But as long as ones' unit of analysis is not the globe and/or the scope of one's

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[10] For instance, if sustainability is equated with self-sufficiency, then clearly a region may be "sustainable" without its sub-

analysis does not encompass all possible resource-sectors, such a problem is bound to arise due to the existence of inside outfluences and cross-sectoral effects.

Consider pesticide use on one farm that contaminates runoff, affecting lands downstream. Here, productivity is being maintained non-decreasing, i.e., sustainability being achieved, in one system at the expense of sustainability in another. As noted before (section **Error! Reference source not found.**), this situation violates the meta-objective of equity, and needs to be acknowledged and dealt with as a problem of inequitable allocation of rights, resources, and power. To some extent, however, one could also say that the situation affects the sustainability of the polluter. While the polluter is not directly affected by the pollution, there might well be unanticipated feedback effects: ecological feedbacks (perhaps pollution of bird habitat downstream affecting natural pest control on the upstream farm) and/or social feedbacks (such as the pollutees organizing and blockading the farm). It seems logical to suggest that an activity that creates such feedbacks is not likely to be as sustainable as an activity that does not. Therefore, I make the following propositions:

Proposition 1: System (or sector) A is said to be less sustainable (with respect to a specific set of sustainability objectives) than system (or sector) B if, all other things being equal, A reduces the sustainability (with respect to the same criteria) of other systems (or sectors) with which it interacts but B does not.

Corollary: If proposition 2 is included in one's definition of sustainability, then micro-level (or

(..continued)

regions being so; or such sustainability may come at the cost of some gains from free trade, i.e., at some cost in productivity. In other cases, it is feared that "pursuit of sustain[ability].. in one resource-sector might ... impinge on [its pursuit] in .. other [sectors]"; for instance, sustainability in agriculture might require more land to be brought under agriculture, and this expansion reduce the sustainability of forestry (Cocklin, 1989). It is not clear, however, that achieving sustainability in forestry requires any specific minimum area. The trade-off appears to be between the productivity benefits from different land-uses.

single-sector) sustainability will ensure macro-level (or multi-sector) sustainability. The converse, however, is not true.

By making reduction of externalities a higher level requirement for sustainability, we obtain a "nested" and more useful formulation of sustainability. In cases where unique orderings (between sustainability of different sectors or between different sustainability attributes) are not possible, some kind of implicit or explicit multi-objective optimization would be necessary. As mentioned earlier, such trade-offs are in fact the raison d'etre for political bodies, and the problem should be left to them rather than misleadingly solved through aggregate indices of well-being.

10.5 Implications for action

Where the externality is "local-local" or "local-global", i.e., where effects of a local action cause clear damage to someone else (local) or many others (global), local sustainability (redefined as in proposition 2) will ensure global sustainability. That is, corollary 2 will hold. But what happens when the problem is "global-global" (i.e., sources and impacts widely dispersed), and also inter-dependent (i.e., the impact from one action depends upon others' actions)? For instance, the climatic impact of a person burning one ton of fossil fuel on her own and others' future well-being will depend upon the amount of fossil fuel burnt by others in the past, present and future.

Current approaches to such "commons" problem include privatization, centralized control, or cooperative communal management. While privatization is impossible in the case of indivisible resources (such as the atmosphere), a central body could determine the global condition for sustainability (e.g., how much CO_2 emission is "sustainable"), and then allocate and enforce quotas. Such an approach may work in cases where the technical issues are relatively straightforward and well-understood, the actors relatively similar in interests and political power, and enforcement costs small (such as, perhaps, the ozone-CFC problem). However, in cases with high transaction costs and dissimilar interests (such as the greenhouse problem), it may either fail or in fact lead to highly unequal outcomes, due to the subversion of the process by the powerful.

An alternative approach to deal with situations of uncertainty and inequality might be to formulate a micro-level principle for macro-level sustainability: *Do unto nature what you would have others do unto it*. Or more precisely,

Consume and pollute at a level and in a manner that, if extrapolated to all other human beings, could sustained by the earth for generations to come.

This approach in no way alleviates the problem of determining what level or manner of consumption could be sustained globally, nor the uncertainty in the outcomes due to the absence of coordination. What it does is provide a criterion for analysis and action that is derived directly and logically from the two fundamental objectives of sustainability and equity. Analytically, such a principle avoids the need to know the actions of all actors before impacts can be assessed. For action, it provides a "fair" basis for allocation of quotas if coordination is achieved, but more importantly, it provides an less-than-arbitrary and "fair" basis for individual action on environmental issues. Rather than decide the sustainability goal and then "negotiate" one's share of responsibilities towards it, this approach ensures that equity is enshrined in the goal at the same time as sustainability.

Thus, we have shown that a global scale is not absolutely necessary for sustainability analysis or action, because firstly, not all sustainability problems require the globe to be the minimum scale of analysis (section 0), nor does a bottom-up approach necessarily lead to "macro-level inconsistencies" (section 0). That a bottom-up approach in action is also highly desirable, if not imperative, would follow from (a) the advantages of de-centralization and limited self-sufficiency (section 0), (b) the diversity of values and interests across communities will make genuine coordination difficult, if not impossible, (c) the inequality of power across communities (both nationally and internationally) will likely result in coordination taking the form of imposition or coercion by the powerful, a situation that militates strongly against the meta-objective of equity. Thus, while not rejecting the notion that most problems have cross-scale origins or effects, and that some problems might be best tackled through global coordination efforts, one needs to shed the "paralysis of analysis", reject the conceptual hegemony of top-down "globalism", and devote more attention to local-level analysis and action.

11 The multi-dimensional nature of sustainability

To summarize part III, sustainability is best thought of as a multi-dimensional characteristic of a socio-environmental system (Figure 5). "What" is to be sustained, viz., productivity, has many physical and psychological/spiritual components. In order to maintain the flow of these components in an unpredictable environment, a system must not only be in dynamic equilibrium but also (or sometimes instead) have the dynamic attributes of reliability, resilience and adaptability. Since no system can be fully closed, the sustainability of a system depends on its endogenous properties as well as the behaviour of exogenous variables and inflows. Finally, we derived the operational requirement that negative inside outfluences should be considered as reducing the sustainability of the given system. Given the continuum of values of most components of this complex framework, systems cannot be thought of as simply "sustainable" or "unsustainable". Further, even to call them "more" or "less" sustainable requires a value-based ranking of the attributes (except in the rare case when two systems differ in only one attribute). But this structured complexity seems much preferable to the prevailing vague and misleading simplicity of the concept.

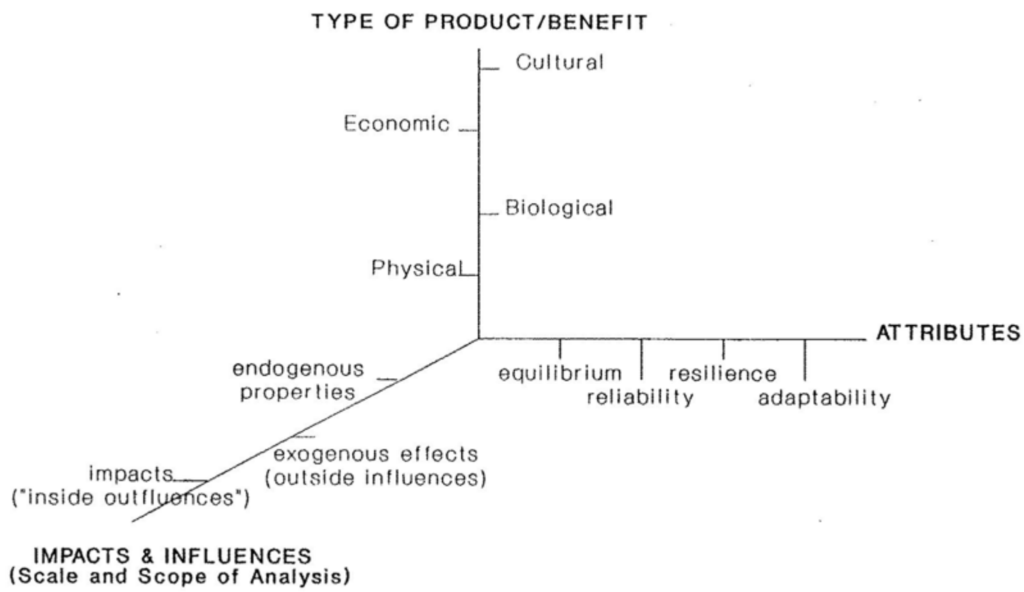

FIGURE 5. **THE MULTIPLE DIMENSIONS OF SUSTAINABILITY**
(In each dimension, elements are arranged from the origin outwards in an approximate order of increasing complexity)

12 Concluding remarks

The approach presented here proposes several new directions for sustainability thinking and discourse. Firstly, it proposes a narrower construction (than the current interpretation of sustainability as "environmental soundness") that makes the concept more coherent, while allowing room for equity concerns to be recognized equally fundamental in environmental issues. Secondly, the approach recognizes the dangers of aggregative, top-down thinking in what is essentially a social construct. It involves understanding and embracing the plurality of preferences, priorities, perceptions, and inequalities of articulation in the determination of the objectives to be sustained, while realizing that such plurality does not prevent useful analysis. Thirdly, it explores the variety of attributes needed to sustain human well-being over time, and shows that the concept of sustainability can provide an over-arching framework for organizing existing work on, and stimulating new insights, into our vision of a desirable future.

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Table 1. What is to be sustained: operational variations in the literature

	Objective to be maintained non-decreasing	Key Assumptions
(1)	Aggregate utility	(1) Utility can be measured for existing individuals; (2) Individual utility can be aggregated "objectively" across individuals, communities and nations; (3) Utility functions of future generations are essentially the same as those of the present; Also implicit are (4) and (5) below.
(2)	Aggregate of natural and human capital	(4) Natural capital can be continuously substituted with human capital; (5) There is no limit to the ability to reduce the energy, material or pollution content of any activity.*
(3-a)	Aggregate Natural capital	(6) Perceptions and priorities regarding the constituents of NC can be aggregated objectively across the current generation; (7) Constant stocks of the constituents of NC will ensure continuous flow of products/services from natural resources to human beings.
(3-b)	All stocks of natural resources and waste assimilation capacities	Assumption (7) above.

* Applies to the case when sustainability is desired forever.

Table 2. Attributes of Sustainability

Attributes	*Criterion*	*Some Indicators*	*Some Recipes*
Dynamic steady-state	Given *average conditions*, magnitude of useful property stays non-diminishing	* time series of productivity * harvest:production ratios * fraction of renewables in total energy use	* maintain harvest # regeneration by reducing demand and increasing production * use renewable energy * recycle exhaustible material resources, using renewable energy
Reliability	Given *usual perturbations* in external conditions, deviations from norm should be infrequent and small	* frequency of deviation from target * range of variation	* internal redundancies, safety margins * control over external variability * loose coupling with external systems
Resilience	Given *major shock or stress*, desired property returns to desired level	* extent of deviation * speed of recovery * difference between pre- and post-shock equilibria	* diversity of components and structure * safety nets, fallbacks * locally dense but globally sparse interconnections
Adaptability	Given *change in average conditions* (abrupt or gradual), desired property continues	* range of options available * adaptation cost * mitigation cost	* maintaining productive potential * investing in monitoring & learning * reducing rates of ecological and social change

Note: Recipe does not necessarily correspond to indicator in that row.