Ecosystem Health: More than a Metaphor?

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ABSTRACT: There is considerable discussion about the nature of the health metaphor as applied to ecosystems. One does not need to accept the analogy of ecosystem as 'organism' to reap insight into the diagnosis of ecosystem ills by applications of approaches pioneered in the health sciences. Ecosystem health can be assessed by the presence or absence of signs ecosystem distress, by direct measures of ecosystem resilience or counteractive capacity, and by evaluation of risks or threats from human activity and natural forces which may decrease the supply of ecological services. The focus of this essay is on what is and what is not implied by the ecosystem health metaphor. It also elaborates a research agenda for this emerging transdiciplinary science. One can argue that beyond the metaphor is the potential for systematic diagnosis of ecosystem ills, development of indicators of ecosystem health, development of early warning indicators of ecosystem dysfunction, development of diagnostic protocols and preventive strategies for maintaining ecological services.

KEYWORDS: Ecosystem stress; early warning indicators; ecosystem health; ecosystem medicine.

INTRODUCTION

The extension of the health concept as both a positive and normative descriptor of the condition of ecosystems is becoming the 'order of the day'. The concept is finding wide application in the policy arena and was highlighted in one of the main principles deriving from the Rio Declaration on Environment and Development (United Nations, 1992). Principle 7 reads in part: 'States shall cooperate in a spirit of global partnership to conserve, protect and restore the health and integrity of the Earth's ecosystem. In view of the different contributions to global environmental degradation, States have common but differentiated responsibilities...'. At regional levels, the health concept has already become part of the working tools for the management of large marine ecosystems (Sherman, 1993), and is well ingrained in the methods relating to forest ecosystem management

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(Kolb et al., 1994). The International Joint Commission (IJC) on Boundary Waters has long had a Standing Committee to develop ecosystem health objectives for the Great Lakes.

These developments have gone hand in hand with advances in both the conceptual and empirical underpinnings for the notion of ecosystem health (e.g. see Costanza et al., [1992] and Rapport et al., [1995]). Indeed, there has been a rash of contributions with metaphorical titles such as 'Healing the planet' (Cairns, Jr., 1992), 'La nature est morte, vive la nature!' (Callicott, 1992a), and 'Planet as Patient' (Somerville, 1995).

The use of the health metaphor as applied to the whole planet can be found in the writings of James Hutton, a Scottish physician and geologist. Hutton, writing in 1788, referred to the earth as a superorganism capable of self-maintenance (Lovelock, 1988). Aldo Leopold, writing in the early 1940s, also made extensive use of the health metaphor in advancing his concept of 'land sickness'. Here the need for developing a systematic practice of land assessment was made explicit and it was suggested that although 'the art of land doctoring is being practised with vigour, the science of land health is a job for the future'. The goal of this enterprise would be to 'determine the ecological parameters within which land may be humanly occupied without making it dysfunctional' (Leopold, 1941).

In the wake of widespread failures to sustain the productivity and integrity of both managed and wild ecosystems Leopold's quest has vastly increased relevance today. Clearly cumulative effects of cultural stress have now resulted in significant quantitative and qualitative changes in the earth's major ecosystems, entailing a great many kinds of ecological dysfunctions. In the face of an unprecedented human population, now estimated to be in excess of 5.6 billion, and a current rate of increase, estimated to be in the neighbourhood of 100 million per annum, pressures on the sustainability of life support systems are bound to escalate.

It is under these dire circumstances that the concept of ecosystem health is enjoying a second flowering. This flowering is not, however, a throwback to the ideas of nature as a 'superorganism'. Rather, the flowering derives from the acceptance of the notion of ecosystem as a system, with system properties that can be (and in many cases have been shown to be) seriously disrupted by human activity. With the recent formation of two International Societies in the area of Ecosystem Health (the Aquatic Ecosystem Health and Management Society, and the International Society for Ecosystem Health), concepts of ecosystem health are bound to play a more central role in a growing number of national and international efforts to rehabilitate the environment.

While there is already some evidence that the use of the health metaphor at the ecosystem level is becoming part of the social agenda, one encounters reluctance if not open hostility to the notion from scientists, and perhaps, ironically, particularly ecologists (e.g., Sutter, 1993). These critics either reject outright the use of the metaphor, claiming that it resurrects the now much discredited view of ecosystem as organism, or they claim that the health metaphor does not apply to the ecosystem level.

To address these concerns, I first outline the nature of the health concept and review its potential applications to the ecosystem level. As Anatol Rapoport has suggested (Rapoport, 1983), the use of metaphor not only has a role in poetry, but also a legitimate place in science. Its function, in both areas, is to stimulate associations, bringing into juxtaposition phenomena that might at first appear to have little connection but that can be seen to be in some way related. In science the value of metaphor lies in pointing to phenomena in apparently different spheres that may bear some structural identity.

At the outset, it is important to recognise that the choice of metaphor may reflect a personal bias or preference and that there is likely a plethora of other approaches that might work equally well. Indeed, currently there are debates among ecologists as to the value of the term ‘ecosystem’, and some ecologists assiduously avoid use of this term. Others, who might well accept the concept of ‘ecosystem’, find the concept of ‘health’ more troublesome because it implies both normative (value judgments) as well as positive aspects. My own bias clearly favours both terms (e.g., Rapport, 1989a; 1992a; 1992b), and my task here is to justify this bias, by restating what is implied by the use of the health concept at the ecosystem level.

Secondly, I reply to the major criticisms that have thus far been advanced to urge caution in acceptance of the concept of ecosystem health. These critiques point to the need to set clearly the proper limits of the use of the metaphor and to recognise fully the nature of the uncertain and dynamic behaviour of these complex systems. Thirdly, I set forth the outline for a ‘research agenda’ for advancing the field of ecosystem health. Further progress will rest not so much on conceptual or philosophical issues as on empirical testing of well formulated hypotheses dealing with specific aspects of interrelationships between ecosystem health, human activity, and human health.

I. THE ECOSYSTEM HEALTH PARADIGM: WHAT IT IS AND WHAT IT IS NOT!

(a) *What is implied by the use of the metaphor*

The development of a new paradigm, as Norton (1992, p.24) suggests, involves ‘... by definition, the creation of a new constellation of axioms and concepts, an alternative set of assumptions, a new method. The paradigmatic approach, therefore, does not perceive the problem simply as one of adding a more holistic criterion of health to the set of concepts that constitute the current, reductionist paradigm. Adopting a new paradigm represents a more radical departure: it is to interpret the world in a new format, a format that is given shape and structure by the development of new concepts and a vocabulary to express them.' Of course not all paradigms are necessarily construable as axiomatic systems. No formal axioms have yet been proposed for ecosystem health. However the health paradigm does satisfy the criteria, interpreting the world in a new format with new concepts and vocabulary. Further as will be shown, the paradigm gives rise to a family of research questions which are highly relevant to societal goals.

The emerging ecosystem health paradigm draws upon a wide spectrum of disciplines, involving various aspects of the health sciences, social sciences and natural sciences. The more evident roots lie in areas of stress ecology, ecosystem science, epidemiology and clinical medicine. These areas all employ systematic approaches to diagnosis and rely on 'early warning' signs of deleterious change. The challenge in these areas is to learn from experience in order to be able to take preventive measures to ensure the viability of ecosystems. It is too often the case that no actions are taken until there is evident loss of ecosystem functions, at which point interventions are often costly and have low probability of success.

There is, of course, not one concept only of ecosystem health, but a number of definitions and models (Rapport 1995a). Some definitions are entirely based on bio-physical properties; other definitions explicitly include socio-economic and human health dimensions (Rapport, 1995b). Concepts of ecosystem health are also influenced by cultural traditions and values. Further, definitions of ecosystem health must take into account specific circumstances, for example, whether the ecosystem is 'managed' or 'wild'. However, even taking these considerable complexities into account, a generic concept of ecosystem health with wide application can be advanced. The following four suppositions are implied by the use of the health paradigm for application to most ecosystem studies:

Supposition 1. *Ecosystem health can be defined in an operational manner and assessments of health status can, at least in part, be based on objective criteria.*

The concept of health is an evolving one. The World Health Organisation has revised its definition on several occasions, each time broadening its domain. Yet the lack of an iron-clad definition has not precluded WHO from registering progress in identifying certain types of human pathologies and potential causes. While Ramon Margalef (pers. communication) has suggested that ecosystems, in contrast to organisms, are at best 'feebly organised' and evidently lack any form of centralised control, it is nevertheless quite possible to assess their condition relative to historic states or desired objectives, using a wide range of science-based methods (Rapport, Gaudet and Calow 1995).

Variants of three basic approaches are widely used:

(i) Absence of signs of ecosystem distress:
In this approach, widely adopted in both the health sciences and ecosystem sciences, a system is presumed 'healthy' if there are no evident signs of disease. This approach naturally has some limitations: e.g., some pathological systems may not display, at least early on, any signs of dysfunction. For terrestrial ecosystems, signs of pathology often include reductions in species diversity (as well as genetic diversity), leaching of nutrients, reduction in primary productivity, shifts in species composition to favour exotic species, increased amplitude of oscillations of component species, increase in disease prevalence, reduction in size of dominant organisms, among others (Odum 1985; Kerr and Dickie, 1984; Karr, 1991; Schaeffer et al., 1988). Many of these signs were identified by Leopold in elaborating his concept of land sickness (Callicott, 1992b). Collectively these signs comprise the 'ecosystem distress syndrome' (EDS) (Rapport, Regier and Hutchinson, 1985). For aquatic systems the signs are the same, except primary productivity and nutrient concentrations increase because of the position of aquatic systems in the landscape. EDS has been documented in several case studies at spatial scales ranging from local bays and estuaries to coastal waters to entire basins (Rapport, 1989b; Hilden and Rapport, 1993).

(ii) Counteractive capacity (resilience):
An alternative measure of ecosystem health involves measurements of the ecosystem's capacity to rebound from normal perturbations or other sources of disturbance (Vogl, 1980; Rapport, 1989a; 1992a; Westman, 1990). It has been suggested that the speed and completeness of recovery after disturbance provides a readily measurable and practical indicator of health (Rapport, 1989a; 1992a, b). This must of course be calibrated to recovery patterns exhibited by specific ecosystems under specified types of disturbance, e.g., the recovery of arid grasslands after drought. One may hypothesise here that stressed ecosystems should exhibit slower and less complete recovery compared with reference systems which are relatively unstressed (Rapport, 1992b).

(iii)
Risks or 'threats':
Health, or more properly 'health risks', may also be assessed by examining known threats (Rapport, 1995a). Case histories relating the magnitudes and sources of stress pressures to subsequent changes in ecosystem structure and function provide a basis for assessing risks of degradation. This methodology has been applied to assessments of risks to fish biodiversity in eastern Canada from acid precipitation (Minns et al., 1990; Minns, 1992). Minns's findings demonstrate that fish biodiversity declines in acidified lakes. In other words, a decrease in biodiversity in fish may signal increased stress on the ecosystem.

Supposition 2. *Systematic diagnosis of ecosystem condition is possible.*

This implies that major factors which have resulted in ecosystem degradation can in some cases be identified, and their influence on the process of ecosystem breakdown can be elucidated.

Diagnostic approaches to cause/effect relations in ecosystem analysis are in fact not new. Among classic examples, two (both from limnology) stand out. G. Evelyn Hutchinson drew attention to a likely role of construction on the Via Appia in causing sudden eutrophication of a mesotrophic Italian lake near Rome (Hutchinson et al., 1970). Edmondson (1961) hypothesised that the primary cause of cultural eutrophication of Lake Washington (Seattle, Washington, USA) was the influx of urban sewage. In this case, with subsequent diversion of the sewage away from the lake, water quality dramatically improved.

Probable causes of ecosystem breakdown have also been identified in reports of more complex situations involving multiple stresses, e.g. the analysis of eutrophication in the Baltic (Elmgren, 1989), eutrophication in the Bay of Quinte (Minns, 1992), desertification in the south-western USA (Whitford, 1995), impacts of acidity on north-eastern North American forests and boreal lakes (Schindler, 1990), transformation in a river and its estuary in the Gulf of Bothnia (Finland) (Hilden and Rapport, 1993), transformations in the Laurentian Great Lakes (Harris et al., 1988). These analyses take into consideration multiple sources of stress with spatial and temporal lags. In such cases, the real work for the ecosystem health concept is to find systematic methods for early diagnosis of major causal factors leading to ecosystem breakdown, and to advance strategies for environmental management which are preventive in nature.

Supposition 3. *Careful study of the aetiology of ecosystems under stress can yield early warning indicators of ecosystem degradation.*

This has been clearly demonstrated in detailed investigations of the impacts of experimental acidification of boreal lakes (Schindler, 1990) and comprehensive studies on the impacts of air pollution on Eastern North American forest ecosystems (Bormann, 1985; Smith, 1981).

Supposition 4. *Ecosystem health practice requires not only diagnostic and curative capabilities but, perhaps most importantly, preventive measures.*

It has been a common experience that once ecosystem degradation has advanced, so that the signs of EDS are obvious, rehabilitation becomes both costly and problematic. Preventive measures, which entail reduction of stress loads before ecosystem resilience has been compromised, are far less costly and more likely to succeed (Maini, 1992). Further, in advocating preventive measures, it should be possible to go beyond the economic argument even if it alone provides sufficient grounds to adopt this approach. One could also add a moral or ethical dimension which presupposes a reverence for life and thus favours conservation of ecosystem integration.

(b) *What is not implied by the use of the metaphor:*

Because the term 'ecosystem health' invokes the use of metaphor, this does not imply that the practice of ecosystem health is an endorsement of the prevailing bio-medical model or the prevailing practice – far from it. In particular, the concept of ecosystem health *does not imply*:

1. *An endorsement of the conventional bio-medical model which attributes 'illness' to a single cause (a disease vector).*

This notion has been by and large discredited in medicine and is not being resurrected here. Clearly, the linkages between causes and effects are complex: there are often many mitigating factors; further, there are often complex temporal and spatial lag effects between stress and response, such that apparent causes may not be the root causes of dysfunction (Rapport and Regier, 1995; Hilden and Rapport, 1993).

2. *An endorsement of the common 'react and cure' approach of western medicine.*

There is no equivalent to giving an ecosystem a pill as a cure, except in very special circumstances (e.g., altering the pH of lakes by adding lime, or fertilising lakes or terrestrial systems to boost productivity). And while there are a number of situations in which interventions of various sorts are called for to rehabilitate damaged ecosystems, the practice of ecosystem health ought to be largely directed toward preventive health. Where interventions must be taken, they ought to be aimed at correcting systemic problems, not used as palliative measures.

3. *An endorsement of medical practice wherein profits are made from illness rather than health*.

Fostering an illness based practice rather than a health based practice tends to discourage actions aimed at health promotion. This all too common feature of human medicine should not serve as the model for ecosystem medicine.

4. *An endorsement of the concept of ecosystem as organism or superorganism.*

Some critics (e.g. Suter, 1993) state categorically that since health is a property of organisms, the use of the metaphor at the ecosystem level implies that ecosystems are superorganisms. This criticism is commonly advanced and underscores a fundamental misunderstanding regarding the use of metaphor. While metaphors are often suggestive they are not meant to be taken literally. The health metaphor draws attention to the fact that ecosystems can become 'ill', that is develop signs of dysfunction resulting from anthropogenic stress. It suggests that methods of analysis and diagnosis developed in the health sciences can be appropriate in whole ecosystem contexts. The metaphor focuses attention on the importance of developing diagnostic protocols and early warning indicators of ecosystems at risk. None of this is intended to resurrect the now defunct

Clementsian view that ecosystems are superorganisms. However it is implied that ecosystems, feebly controlled and passively organised as they may be, are characterised by some degree of internal integration which, in response to stress, can break down with a subsequent loss of ecological services (Cairns, Jr. and Pratt, 1995). Evaluation of ecosystem condition and attendant risks of degradation can be carried out with similar methods employed by the health sciences. These involve the development of expert systems and the use of an array of validated special purpose indicators for both diagnostic and prognostic purposes.

5. *An endorsement of the common practice in which health assessments and responsibilities reside entirely with medical professionals, and patients takes little or no responsibility for decisions affecting their lives.*

Clearly ecosystem health, as human health, ought not to rely solely on the advice of professionals, but ought to incorporate the values and desires of the people affected by the outcomes.

II. CRITICISMS OF THE ECOSYSTEM HEALTH PARADIGM

Critics have tended to focused on three major aspects:

1. *Health, being a concept developed for application in clinical and epidemiological medicine, is not well suited for whole ecosystems* (Suter, 1993).

Some critics claim that any effort to apply health concepts to whole ecosystems suggests that ecosystems are to be viewed as ‘organic wholes’ – as superorganisms – with homeostatic or homeorhetic mechanisms which serve to regulate and buffer the system in the face of external perturbations. As already mentioned, since the Clementsian organismic view of nature has been by-and-large rejected by most contemporary ecologists, there is considerable scepticism if not outright hostility towards a framework which appears to bring back the organismic approach, albeit by ‘the back door’.

The health metaphor suggests a holistic approach to ecosystem function, but this does not imply that ecosystems display, in general, anything approximating the degree of homeostatic control characteristic of organisms (Holling, 1985; 1993; Botkin, 1990; Rapport and Regier, 1995). Ecosystems are generally at best feebly and passively controlled, while organisms are generally controlled by strong internal feedbacks and goal directed activity. However one can nonetheless derive benefits from applications of the health metaphor at the ecosystem level.

The validity of the comparison derives from the fact that both ecosystems and organisms display common properties of complex systems. Yet the mechanisms responsible are vastly different. It is sufficient that both ecosystems and organisms have some capability to maintain or restore cybernetic functions when destabilised by external forces. Both systems are amenable to 'doctoring' or 'management', when under stress, and to limited degrees, both systems may be 'rehabilitated' through various human intervention.

2. *Ecosystems often exhibit highly variable, even chaotic behaviour. Under these circumstances, 'norms' are difficult if not impossible to establish* (Kelly and Harwell, 1989; Calow, 1992).

Because most ecosystems display complex dynamic and evolutionary trajectories, there is a difficulty in identifying the differential impact of stress caused by human activity (Carpenter, 1990). Another difficulty stems from the fact that ecosystems are unique, and there are insufficient 'replicates' by which to establish normal ranges of variability for key parameters (Calow, 1992; Kelly and Harwell, 1989; Minns, 1992). Thus Kelly and Harwell (1989) conclude that while the 'goal of environmental protection is essentially to ensure the "health" of ecosystems', the health metaphor is unsuitable because: '...unlike indicators of adverse human health effects, there are no comparable integrative, simple measures or indices that show the effects of disturbances on ecosystems'. They go on to suggest:

> …attempts at an analogy of ecological health to human health have not been satisfying, in part because the exposure of ecosystems to stress is very complex...; in part because ecosystems are more diverse and more complex than the human metabolic systems;... and in part because ecosystems are much less internally coordinated and less able to respond to stress by controlled compensatory mechanisms that engender homeostasis of the systems... If ecosystems truly could be seen as superorganisms, where a few key components or processes reflected the state of being of the ecosystem-superorganism, then ecological response and recovery predictions in principle could be as reliable as human health check-ups and prognoses. But the reality is that predictive ecology lags far behind because ecological systems are less robustly defined, their dynamics thus being inherently less tractable, and their state not so easily fully characterised. (Kelly and Harwell 1989, p.13)

Minns (1992, p.110) raises a similar concern, suggesting that there is little consensus on expected values of various indicators that have been suggested as characterising ecosystem health, and that the complex interactions among indicators are rarely addressed.

These are valid concerns although it might be argued that in recent years it has become increasingly possible to detect ecosystem breakdown with sensitive holistic measures. Recent studies (e.g. Schindler, 1990; Hilden and Rapport, 1993; Elmgren, 1989) suggest that careful analysis of long-term data sets ought to permit one to distinguish stressed from unstressed systems and to relate particular stress pressures to ecosystem transformations.

Analysis of data on long-term behaviour of ecosystems suggest that rates of flux (energy, nutrients) are a more sensitive indicator of stress in some situations, while changes in structure (soils, biotic composition) are more sensitive for other situations (Rapport, 1992a). Such subtleties add immense challenges for analysis. For example, while Schindler (1987) states that it may be years before sufficient data is accumulated to 'confidently distinguish between natural variation and low-level effects of perturbations on ecosystems', in work published only three years later, Schindler (1990) is confident that sufficient long term data can differentiate pathological states from normal. Further, even in his earlier work, Schindler (1987) suggests that advances in palaeoecology allow one to characterise abnormal ecosystem states. Recent advances in ecological applications of remote sensing hold equal promise (Mouat, 1995; Whitford and Rapport, 1996). Abnormal system states of course do not necessarily imply unhealthy states – that depends very much on whether the abnormalities have made the system dysfunctional and consequently impaired ecological services.

Moreover, in raising the question of the lack of apparent norms of ecosystem condition, there is the hidden assumption that norms are well established in the medical field. Yet in both human and veterinary medicine, there too exists a large area of uncertainty with respect to 'norms'. Contrary to common belief, well established normal bounds (with the exception of temperature) are not common. Most critical functions (e.g. metabolism, heart rate, blood pressure, mobility) vary significantly in the same individual over time, and between individuals.

There is no doubt, however, that this variability is better characterised for organisms than for ecosystems. With organisms there is potentially a large number of replicates, this is seldom the case for ecosystems. One exception, however, is in the case of inland lakes, which in some regions are of sufficient number to define the variability reasonably well (Kratz et al., 1995; Minns et al., 1990). Within terrestrial systems, sub-samples (e.g., individual stands within the forest) provide a basis for establishment of variability in some key parameters – e.g. above-ground biomass, soil nutrients, species diversity, size and age distributions, etc.

Establishing 'norms' for ecosystems (which obviously will vary by type of system and geographical zone) is an ongoing challenge. New statistical approaches (Carpenter, 1990), coupled with increased availability of long term data sets for major ecosystems, will provide the basic material to develop a clearer picture of the normal bounds for specific systems.

Ehrenfeld (1992, p.141) raises the question of whether normal bounds will have to be established for each ecosystem, or community, owing to the fact that '...communities vary greatly, with some occurring at the equilibrium end of the range, some at the non-equilibrium end, and others at all degrees in between'. Most systems are, in fact, operating at the 'non-equilibrium end' of the spectrum and thereby exhibit a large degree of variability. Long-term data are required so that this range of normal variability can be more confidently established. In most ecosystems, the range of values for particular parameters also varies with the stages of ecosystem development and evolution (Odum, 1969; 1985).

In view of these considerable complexities, how can one identify generic properties which serve to maintain functional and structural ecological integrity (Rapport and Regier, 1995)? Properties that ought to be preserved might include characteristic levels (rates) of primary productivity, nutrient cycling, biotic diversity and species composition, size distributions of biota, amplitudes and periodicity of fluctuations in key biotic and abiotic components, and concentrations of toxic substances. Tracking these variables over time (and space), it becomes possible to evaluate particular situations in terms of whether the system is moving towards or away from culturally productive systems, i.e., systems that maintain their organisation, resilience and flow of culturally desired ecological services (Hilden and Rapport, 1993; Whitford, 1995; Schindler, 1990).

Interestingly enough, the crucial question of whether 'norms' can be established for ecosystems was raised half a century ago by Aldo Leopold. He suggested that principles of 'land health' needed to be established with reference to norms, and that in this endeavour, wilderness 'may serve as a base-datum for land health' (Callicott, 1992b, p.43). One should add, however, that not all systems can be returned to their previous pristine state, and that rehabilitation may involve restructuring the system such that another, but equally acceptable, state is reached (Rapport and Regier, 1995). Furthermore there may be no reason to accept in all cases that *a priori* wilderness is healthy in the broad sense of being supportive of human health and economic activity.

A complication arises owing to the fact that for many ecosystems there exist alternative states which may be self-perpetuating. Good examples may be found in the history of the Laurentian Lower Great Lakes. In various periods these lakes have sustained a fishery dominated by large benthics, and in other periods these lakes have been dominated by small pelagics. Presently there is a fish community delicately balanced among introduced species: salmon (*Oncorhynchus spp.*), alewife (*Alosa pseudoharengus*) and smelt (*Osmerus mordax*). The present state appears self-perpetuating. Would it however be considered a healthy community?

For most ecosystems, the notion of a single 'climax' state has given way to notions of alternative stable states (Rapport and Regier, 1995; Holling, 1993). Here ecosystem health refers not to a particular ecosystem condition, but rather to a class of system properties covering one or more alternative self-perpetuating states. To determine if the system is 'healthy' requires criteria which are independent of the particular form sustainable systems might take, but examine generic processes and structure.

3. *'Health' is always, at root, a value judgment. Therefore it has no validity in scientific assessments.*

It is a much misunderstood aspect of the health sciences that one often has the impression that human health determinations are wholly objective – a simple matter of clinical test results. The opposite impression is held for ecosystem assessments. Here health assessments are thought to be wholly subjective, largely dependent on social values.

In actuality, social values play a prominent role in *all* health assessments. The seeming 'objectivity' (from the layman's perspective) in human and veterinary arenas reflects general agreement on the values that govern these types of assessment. The notion advanced by René Dubos (1968) that health is 'a *modus vivendi*, enabling imperfect man to achieve a rewarding and not too painful existence' likely reflects a generally shared social value. Porn (1984), however, suggests that the criteria for health be expanded further to incorporate judgments by the individual with respect to his or her life goals. In the end, human health assessments have validity only with respect to what individuals deem a worthwhile, i.e. 'desirable' life.

Similarly, human values play a pivotal role in determining what constitutes a healthy ecosystem (Rapport, 1992b). One might flag various classes of values – e.g., those that are directly concerned with satisfying human material needs; those that are concerned with satisfying aesthetic, spiritual, cultural needs; those that are concerned with the sustainabililty of the ecosystem as such. The challenge for the practice of ecosystem health is to specify desired states more clearly and less equivocally so that these values become criteria for assessment. The admission that values do and should play a fundamental role in ecosystem health assessment is not tantamount to declaring that any possible state of the system is healthy if society declares it so! This would be serious misreading of the role of values in health assessments.

Obviously, if exploitation of an ecosystem for a particular 'service' were at the expense of other elements vital to the healthy functioning of the system, this would not confer overall health. Utilists (Regier, 1993) may foster a sustainable harvest of merchantable timber, but do so at the cost of loss of wildlife, aesthetics, water quality and other services of forested ecosystems. This result would hardly be judged consistent with maintaining ecosystem health. Clearly the criteria for ecosystem health cannot contravene the criteria for sustaining the functioning of the system, which include mechanisms for self-maintenance and repair.

However, within those overriding constraints there are a range of ecosystem conditions which might be deemed satisfactory, depending on the prevailing societal values. For example, a forest might be managed as a source of commercial timber, as a reservoir for biological diversity, as a sanctuary for indigenous peoples, as a contributor to regional and global climate, or to meet several or more of these goals. The structure and function of the managed forest would of course depend on the nature of the goals be achieved. However, healthy forests are clearly more than suppliers of merchantable timber – they are also critical in sustaining regional landscapes and human cultures.

That short term goals satisfying human needs for material well-being may be at odds with the longer term goals of sustaining ecosystem functions and a broad range of ecological services, is all too commonplace. Callicott (1992b) raises these issues in stark terms:

> What is wrong, objectively wrong, with urban sprawl, oil slicks, global warming, or, for that matter, abrupt, massive, anthropogenic species extinction – other than that these things offend the quaint tastes of a few natural antiquarians? Most people prefer shopping malls and dog tracks to wetlands and old-growth forests. Why should their tastes, however vulgar, not prevail in a free market and democratic policy? (Callicott, 1992b, p.46)

Callicott argues here that the concept of ecosystem health serves as an important rescue mission by providing a strong rebuttal to the commonly stated argument that since nature is dynamic and since biotic communities may be nothing more than a fortuitous collection of species, and further, since extinction is commonplace throughout evolutionary history, there is nothing 'wrong' with change of any sort. That argument is flawed in that environmental changes which reduce the flow of ecological services from ecosystems (Rapport, 1995c) can readily be shown to have adverse consequences for human kind (Regier and Baskerville, 1986). Such changes generally signal a reduction in health, and this often occurs at the very time a specific output from the system is boosted, at least temporarily, in support of short run economic goals.

Thus societal values have a pivotal role in determining the range of acceptable healthy states for ecosystems. However, this role for societal values does not contravene the bio-physical requirements for persistence of particular ecosystems, nor does it contravene the need for methods, based on science, enabling reliable diagnosis of ecosystem pathologies and identification of the primary causal factors involved in ecosystem transformation. Once values are identified which shape 'objectives' for maintenance or rehabilitation of ecosystems, scientifically based analysis can be undertaken to determine whether achieving these objectives is compatible with the persistence of the particular ecosystem and with maintaining, or at least not contributing to degradation of the health of neighbouring ecosystems (Rapport, 1995c).

III. A RESEARCH AGENDA FOR ECOSYSTEM HEALTH

Ehrenfeld (1993, p.15) suggests that 'health is a bridging concept connecting two worlds – it is not operational within science if you try to pin it down, yet it can help foster the necessary process of enabling scientists and non-scientists to communicate with each other'. I would go somewhat further by suggesting that the health concept has given rise to research questions which are operational within science and it has been instrumental in the development of new approaches to monitoring and evaluating the sustainability of large-scale ecosystems (Rapport, Gaudet and Calow, 1995). In this section I sketch some of the main areas that are particularly amenable to research.

Ecosystem Health and Values

The proposed 'Research Agenda' for ecosystem health (1995a, 1995b) would not side-step this important issue, but rather, would meet it head on. In my view, the use of the health metaphor goes far beyond fostering 'the necessary process of enabling scientists and non-scientists to communicate with each other'. Clearly, values are at the centre of health evaluations, but this does not preclude the development of a sound basis for diagnostic procedures and a sound basis for health assessments based on explicit value criteria for health which arise from a consideration of social values.

Assessment of ecosystem health involves, as a first step, determining assessment criteria – these criteria are most often set by a combination of societal values and system constraints. For example, in assessing landscape health there is a need to specify what the public wishes to protect and whether protecting those elements assures a sustainable landscape. The concept of land health of course might well provide direction as to what might be of value. Once this is determined, then it becomes a scientific question to determine which human activities are compatible with maintaining these values and the continuity of the ecosystem.

The role of indicators is critical to carrying out this step. The need here is for the identification and validation of key indicators that are linked with preserving the specified ecosystem (landscape values) and are sensitive to activities which degrade or limit ecosystem services relating to these values. Generally speaking, there are any number of proposed indicators, but few that are validated with respect to sensitivity to stress. New statistical techniques are required to establish causal relationships between stress loadings and ecosystem transformation in these 'repeatable' but not replicable events on large-scale ecosystems. Perhaps the ecosystem equivalent of 'HEALTH SMART' can be developed, with considerable savings on costs of health care for the ecosystem.

Indicator Identification and Classification

A basic component of many research projects in the ecosystem health field is the identification of indicators by which systems may be evaluated. It is my thesis that this enterprise could draw heavily upon approaches already well developed in human and veterinary medicine. For example, in the health sciences, various classes of indicators can be distinguished, each with specific utility. I refer here to: general screening indicators, diagnostic indicators, risk assessment indicators and fitness measures (Rapport et al., 1981; Rapport, 1983; Rapport, 1989b).

The identification of key measures ought to be based on in-depth knowledge of system functions, identifying those crucial to the overall integrity of the system (Rapport, 1989b; Hilden and Rapport, 1993). What needs better articulation is the rationale or basis for indicator selection. It is easy enough to proclaim a list of indicators (commonly these lists include aspects of primary production, nutrient concentrations, biotic composition and diversity, etc.), but more difficult to build a solid rationale as to the significance of the particular measures, individually and collectively. This requires first and foremost addressing the question of how each chosen indicator is reflective of a wider set of ecosystem properties. It also requires evaluation that indicators are independent of one another, e.g., that they are not auto-correlated (e.g., size of dominant species and selection for high reproductive rates would be manifestations of the same condition as would be nutrient concentrations and primary productivity). Further, one needs to establish means of validation for the set of indicators; i.e. how well does the set as a whole provide a reliable basis for characterising the health particular ecosystems with respect to particular objectives. Finally, one needs to carefully distinguish between different purposes for which indicators might be used. Each purpose might require a separate set of indicators, e.g., for general screening, early warning, risk assessment, etc.

'Early Warning' Indicators

As an example of indicator classification, consider the development of 'early warning' indicators of ecosystem pathology. There are several approaches to early warning indicators. One approach involves identification of indicator species, i.e., those sensitive species whose behaviour or mortality is affected in a pronounced way with the onset of stress. It has been shown, for example, that inhibition in the growth of feather moss lichens can be triggered by air-pollution, and such inhibition may serve as an early indicator of ensuing damage to forest ecosystems (Hutchinson and Scott, 1988). At the community level sublittoral macrophytes have been used to indicate the early impacts of eutrophication on aquatic ecosystems (Kangas et al., 1982; Ronnberg et al., 1985).

Early warning indicators can also be developed from assessing risks or threats to ecosystem health (Minns et al. 1990; Minns 1992). Here forecasting models can be developed which relate specific stresses to probable effects. Once the connection is made between stress and response, it is possible to monitor cumulative stress loads and set safe levels in efforts to prevent or minimise ecosystem degradation.

Direct measures of ecosystem resilience may also serve as an early warning indicator of stress impacts on ecosystems. Ecosystems are continually being 'tested' in their capabilities to recover from normal perturbations. It has been hypothesised (Rapport, 1992b) and confirmed in recent empirical studies on semi-arid grassland responses to periodic drought (Rapport and Whitford, 1996) that stressed ecosystems recover less rapidly than unstressed systems when challenged by natural disturbances. The less rapid rebound (or reduced counteractive capacity, Rapport, 1989b) itself may be an early warning indicator of stress impacts on ecosystems

Sensitivity and Validation

Questions of sensitivity offer considerable scope for empirical work. By sensitivity, one refers to the response of the particular indicator to changes in the level of chronic or acute stress. Indicators are likely to vary considerably in their sensitivity to particular stresses, and to the same stress in different ecosystems. Thus sensitivity is likely to be highly dependent on the nature of the stress, levels of stress (both chronic and acute), and the nature of the recipient ecosystem.

A key stumbling block to investigations of sensitivity of indicators in field situations is the lack of appropriate statistical methodologies. In order to infer causality – the necessary precondition for testing sensitivity – one normally requires statistical methods comparing ‘experimental’ with ‘control’. Since in nature there are seldom sufficient ‘replicates’ for applying classical statistical techniques, new methodologies are required to effectively deal with ‘one of a kind’ events. Given the natural variability that is inherent in ecosystems, and the complex dynamics of the system, this proves a difficult, but not impossible challenge. Some promising avenues in the development of statistical and mathematical methods for evaluation and diagnosis include the applications of Baysean models, time series analysis (Carpenter, 1990), fuzzy logic (Bezdek, 1987; Terano et al., 1987) among many others (Patil, 1996).

Validation of indicators ought to be an essential element of indicator research. Research is needed to determine the sequence of events from the initial appearance of indicator(s) to the ensuing consequences to the system. For example, if several key indicators point to ecosystem breakdown, does the ensuing history of the system confirm that diagnosis? That is, in the absence of interventions or stress reductions, do the signs of ecosystem breakdown become more pervasive?

Questions of Scale

Many indicators are based on measurements taken at sampling stations representative of very small areas. This poses obvious difficulties for assessing large-scale ecosystem conditions, or landscapes. Here, work is needed to determine to what extent it is permissible to make inferences across scales from laboratory to small scale field studies to systems of intermediate and large scale. This subject is the focus of laboratory and field investigations on the ecology of Chesapeake Bay as part of the University of Maryland’s Multiscale Experimental Ecosystem Research Center (Mageau, Costanza and Ulanowicz, 1995).

Diagnostic Protocols

There are a number of formidable barriers to establishing practical diagnostic protocols for ecosystems under stress. These include:

(i) The complex dynamic behaviour of the system, at best only partially understood, rendering early detection of 'abnormalities' difficult particularly in response to low level chronic stress;

(ii) The fact that so many types of stress eventually result in common signs of distress (Rapport et al., 1985; Odum, 1985) implies that stress-specific signs occur at earlier stages of ecosystem breakdown, but at these stages detection of abnormalities is generally more difficult;

(iii) Often a large number of different stress factors impinge upon the same ecosystem. Thus diagnostic protocols for ecosystems would in many cases 'rule in' a number of potential stress factors, resulting in considerable uncertainty as to the identification of the major stress forces.

These difficulties notwithstanding, it ought to be possible to establish generic protocols for the diagnosis of ecosystems under stress. What is crucial in this process is to record the 'patient history' at the very early stages of ecosystem breakdown – for at later stages the appearance of a more generalised distress syndrome is not informative as to particular causes. Well documented case histories of the type conducted by Schindler (1990) and Hilden and Rapport (1993) are invaluable for establishing the sequence of events that can be detected at ecosystem levels from the early onset of low-level anthropogenic stress to the final stages of chronic intense stress. These studies suggest that careful documentation of temporal and spatial consequences of stress yields sufficient information to establish, with a high likelihood, casual linkages. Further, these analyses lead to hypotheses of mechanisms which link the known spatial/temporal patterns of stress factors to the spatial/temporal patterns of ecosystem response.

Bio-markers

Here one refers to biochemical changes in individual organisms, providing one approach to early warning diagnostic indicators of certain well defined classes of chemical stress on ecosystems. Bio-markers are well suited to detection of cumulative effects of exposure to toxic substances. Less developed are bio-markers associated early on with other forms of stress.

Taxonomy of Ecosystem Ills

One of the critical areas in the development of a science are systems of classification. Phenomena need to be catalogued, compared and related. This is particularly true for ecosystem dysfunctions, of which there appear to be a bewildering number. Clearly their diagnosis and the formulation of strategies for rehabilitation of damaged systems will draw upon available case histories of 'similar type'. What 'similar type' means for ecosystem pathology (Rapport, 1989b), remains to be explored. Naturally, for large-scale ecosystems there are no precisely similar circumstances. Yet experience has shown that sufficient common features can be identified so that broad categories of ills may be developed. Our taxonomy of ecosystem ills remains primitive. Commonly one distinguishes between eutrophication, acidification, desertification, salinisation, overharvesting, but not within these broad categories. The challenge is to articulate broad classes of ecosystem ills which are based on a coherent logical system.

CONCLUDING REMARKS

At the level of national policy, regional development and local environmental concerns, maintaining and enhancing ecosystem health has become recognised as a major objective. Indeed it might be said that ecosystem health is the 'bottom line' guiding sustainable development – for if the health of the environment is compromised, everything else is undermined (Rapport, 1995c).

In this context, the value of the health metaphor appears to be two-fold:

(i) It has provided a powerful language by which to convey major environmental concerns in a focused, action-oriented way. The underlying model is holistic, encouraging a description of the cumulative impacts from both human and non-human sources on ecosystem health and integrity.

(ii) It has encouraged the transfer of concepts and analytical methods from the health sciences to ecosystem sciences (and to a lesser extent, conversely), including importantly, a focus on preventive as well as curative health practices. This provides a scientific basis for assessing and monitoring the health of large-scale ecosystems (Rapport, Gaudet and Calow, 1995).

The paradigm places emphasis on systematic case histories, use of syndromes (groups of indicators) to identify ecosystem distress, and the use of various classes of indicators which serve a range of purposes from diagnostic to general screening.

Critics of the paradigm question its utility in advancing ecosystem science. They take note of the failures of earlier efforts to assert that ecosystems are like organisms – which they are decidedly not. They then argue that – given that ecosystems are different than organisms, and given that the health sciences is primarily geared to treatment of individual organisms – the use of the analogy is invalid. Here I believe there is a fundamental misunderstanding as to the value of analogical reasoning. It is not essential, in my view, that the systems being compared be identical in all respects. What is crucial is that they share some properties – such that methodologies applicable to one are applicable to the other

– at least with suitable modifications to reflect the unique character of the systems to which they are applied.

Clearly, ecosystems share the property with organisms that they can and often do become dehabilitated, and although the causal mechanisms differ, methods of detection (i.e. the use of signs, syndromes, early warning indicators, etc.) are similar. Further, diagnostic protocols which rule in and rule out potential causal factors are also highly applicable to both systems. Finally, the very concept of health itself – as a reflection of the physical state of the system and the social evaluation of that state – is central to assessments both of individual organisms and ecosystems. While critics point to the non-scientific aspects (i.e., the value judgments that go into defining 'health'), this is part of the reality of both human medicine and ecosystem medicine, and in this sense is a strength rather than a weakness of the metaphor.

The key challenges ahead are to move beyond metaphor into a soundly based practice of ecosystem health assessment, diagnosis, and preventive strategies. In so doing, explicit criteria for evaluating health must be developed. Taxonomies of ecosystem ills need further refinement and indicators of risk, and early warning of the loss of ecosystem resilience need to be validated.

That ecosystem health clearly ought to strive for a preventive approach – the only realistic goal in light of the high social and economic costs of restoration and rehabilitation – and the fact that human medicine has been largely curative rather than preventive, provides no justification for abandoning the paradigm. Rather it is grounds for learning from past mistakes in both the health sciences and ecosystem sciences. Adoption of ecosystem health as a societal goal and as a basis for a new approach to environmental management does not equate to acceptance of all aspects of the current practice of human medicine. Advances in ecosystem health can only benefit by taking note of short-comings of the bio-medical model and its practice and attempting to chart a better course.

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