NATIONAL ROUND TABLE ON THE ENVIRONMENT AND THE ECONOMY
TABLE RONDE NATIONALE SUR L'ENVIRONNEMENT ET L'ÉCONOMIE

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Canada

Approaches to Reporting on Ecosystem Health

-- DRAFT --

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The Concept of Ecosystem Health

Economic development has radically transformed and materially enriched, beyond measure, the life of the privileged 20% of humankind. But for the 80% that lives at or near subsistence levels, economic development has had little effect -- it may have even impoverished them further. However, where there is gain there is cost, and for both rich and poor nations alike, unprecedented degradation of the environment have accompanied economic development. This degradations is now exacting a heavy toll. Preventing that toll from rising further and completely sapping the 'life blood' of living systems may prove to be the ultimate challenge for the survival of humankind.

In a bygone era, where human populations were only a fraction of those today, and the technological capacity for inflicting substantive damage to natural systems was limited to local scales, simple assumptions that detached economic life from the underlying productive capacity of the environment were not overly violated. Today, although economic texts still proclaim that the circular flow of money and goods feeds only upon itself, it is well known that economic gain has been at the expense of much of the accumulated stock of ecological capital. In drawing down that capital, society has accumulated an enormous environmental debt.

The size of the environmental debt is being measured in terms of the heightened rates of species extinction -- estimated at 40,000/yr (mainly insects and invertebrates), the disappearance of whole ecosystems, transformation of productive drylands to deserts, losses in agricultural fertility, etc.. It may also be measured in human misery where in many poor countries, there are acute shortages of firewood, food, and increased frequencies of famines and floods, catastrophic epidemics, and wars.

The global prospect facing humankind is one of considerable risk to the survival of our own species. In view of these ominous events, and dire predictions, the search for "sustainable development" sounds a more optimistic note, and an intriguing one.

Ecologically Sustainable Development

What is meant by "sustainable development"? Clearly it cannot be taken in the conventional sense of economics -- that is, expansion of the physical structure of the built environment, accompanied by an ever expanding population, development cannot be sustained, at least not indefinitely. The finite resources the earth, the limited capacity to receive wastes, and already overstressed ecosystems require that any sustainable future be designed on an altogether different basis.

It is this different basis that provides a legitimate use of the term "sustainable development", where the term 'development' here is interpreted to mean "the capacity (of an ecosystem) to respond positively to change and opportunity" or "maintenance of the dynamic capacity to respond adaptively" (Golly, 1990, p. 16). In this context, the key property to be sustained is the capability of natural systems to maintain their dynamic capacity to respond adaptively to perturbations and surprise. This requires that primary attention be given to the goal of preservation, maintenance and enhancement of the health of the earth's large-scale ecosystems. Achieving these goals calls for development of an integrated science, involving important aspects of the natural sciences, social sciences and health sciences

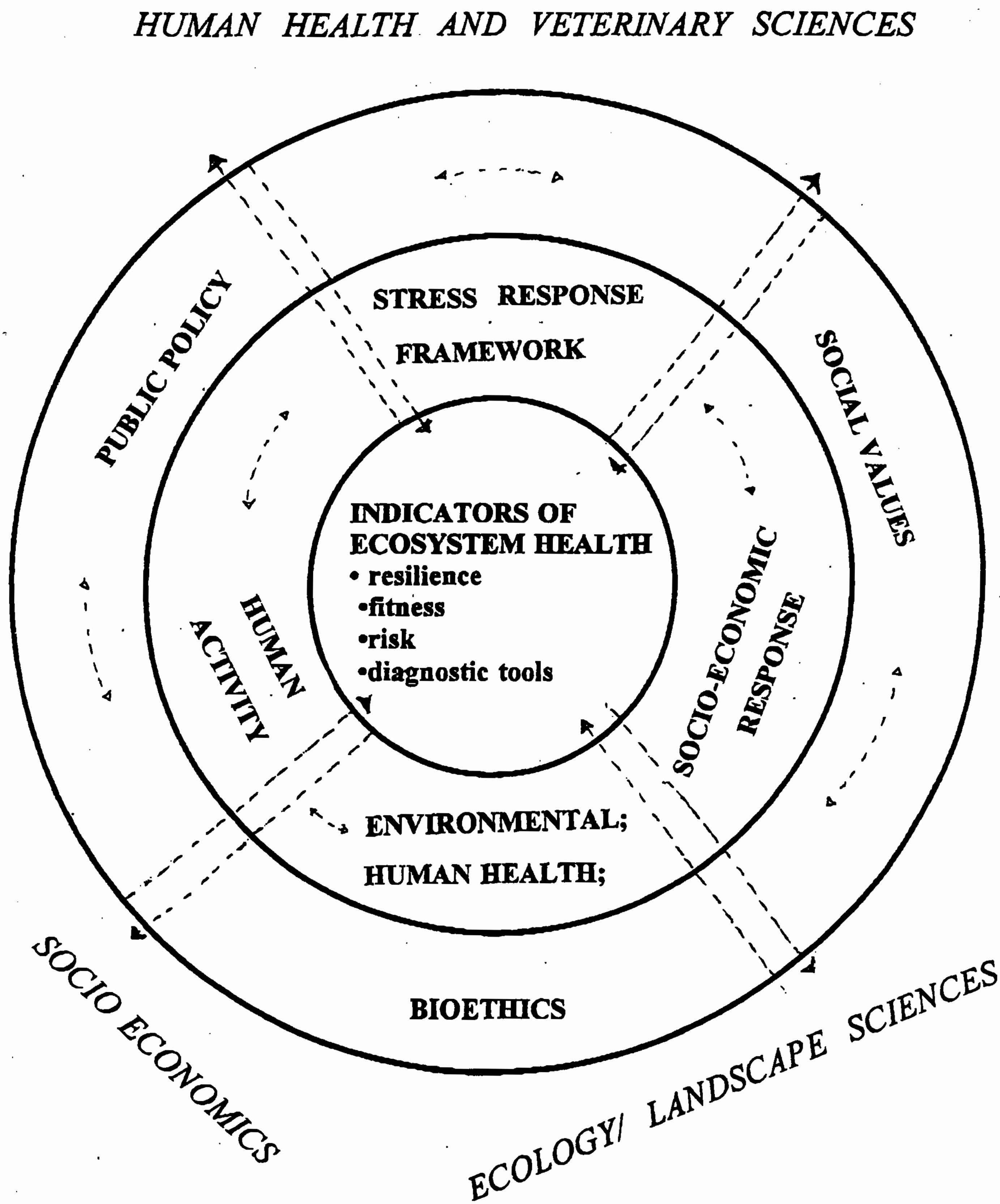
In **Figure I**, the conceptual basis for an integrated science of ecosystem health is portrayed. Ecosystem health is here defined, not only in conventional ecological terms, but also in socio-economic and human health terms. Humans and their social and physical infrastructure are deemed part of and not separable from the ecosystem. These components are interactive. Interpreting this figure might be made clearer in the context of a particular example.

A Transdisciplinary Perspective

Take the case of Canadian agriculture: in recent evaluations of agro-ecosystems, diametrically opposite conclusions were reached reflecting two partial perspectives. In a preface to a 1989 policy review of agricultural activities in Canada, the Honorable Don Mazankowski, Minister of Agriculture noted that "We have a sound agri-food industry that is doing a good job. Let us grow together. Let us build on our successes..."(Agriculture Canada, 1989). This assessment of Canadian agriculture was based largely on gains in productivity and alleged improvements in efficiency. While the report acknowledges structural adjustments and the need for environmental sustainability, the over-riding tone of the policy review is that the agri-food industry should focus on becoming more competitive and profitable.

Figure 1: A Transdisciplinary Framework for Assessing Ecosystem Health.

Taken from: Rapport, D.J. 1994 Ecosystem Health: More Than A Metaphor?, Environmental Values (under review).



In a 1992 report of the Science Council of Canada (Science Council, 1992), however, a very different picture was drawn. While acknowledging productivity gains, the Council underscored the serious "vulnerability of a system driven by agricultural policies that emphasize increased production at the expense of environmental considerations." If one were to examine agriculture activities from a public health perspective, yet another vision of the realities in agriculture would be revealed. The rate of disabling injuries among farm workers is higher even than among construction workers (Schwing & Albers, 1980).

The apparent inconsistencies in these assessments are derived from the fact that each is based on a limited view of what constitutes agroecosytem health. Clearly, ecosystem health comprises biophysical integrity, socio-economic well-being and human health. Each of these domains has its own set of indicators, and a comprehensive analysis of the health of agriculture needs to consider all three major aspects. While health in one domain may in the short run be supported at the cost of health in another, over time the system becomes unsustainable if health in any domain is compromised.

If ecosystem health is to provide the measure of sustainability, it needs careful definition. Does the metaphor drawn from the health sciences have any practical significance for the environmental sciences? Some critics still claim the metaphor is baseless owing to the enormous difference between an organism and an ecosystem (Suter, 1993; Kelly & Harwell, 1989). Yet, who would deny that the 'health' of many regional ecosystems has not been compromised?

Obviously, to dismiss the notion of ecosystem health on the grounds that the metaphor cannot be taken literally, is to fundamentally misunderstand the purpose and value of the use of metaphor in science (Rapoport, 1983). While ecosystems are not organisms nor 'superorganisms', they are nonetheless highly organized systems which have often become degraded through the influences of human activity. This results in a reduction in 'ecosystem services'. To prevent such damage and restore it where it already has occurred is one of the primary goals of the transdisciplinary approach of ecosystem health and medicine. What is sought is development and elaboration of methods for diagnosis, prognosis and treatment of ecosystems under stress. The goals of this integrated science are to identify methods of preventative ecosystem care, so that interventions can be taken before ecosystem resilience is compromised and effective treatments become more problematic and entail considerably higher costs and risks (Maini, 1992).

While there is no generally accepted definition of ecosystem health, there are a variety of proposed definitions -- most of which show a great deal of congruence (Rapport, 1989a, 1992a; Costanza, 1992; Calow, 1992). Further, there is a substantive literature developing around a related concept, namely that of "ecosystem integrity" -- which, if not identical to the concept of health, is certainly largely consistent with it (Karr, 1991; Woodley et al, 1993). To mirror the definition of human health given by the World Health Organization, ecosystem health may be said to be a 'resource', enabling ecosystems to adapt to changing conditions and evolve (University of Guelph, 1993).

Ecosystem Health As The Bottom Line

'Sustainable development', as a code word meaning 'the capacity to respond positively to change' (Golly, 1990), implies that a precondition for achieving this is the maintenance of ecosystem health. The supposition is that ecosystems which are healthy are better buffered against perturbations and are more likely to recover from surprise events. Integrative indicators of ecosystem health may be found in two key attributes, both of which were compromised, historically, in the course of economic development. One of these is the supply of ecosystem services (Cairns, Jr. & Pratt, 1994); the other, the preservation of management options (Whitford, 1994).

The Supply of Ecosystem Services

Ecosystem services is an amorphous term -- referring to all aspects of ecosystems that have value, although not necessarily measured in economic terms. These include, importantly: productivity (both primary and secondary); biodiversity (at all levels -- i.e., genetic, biotic, habitat); water quality; aesthetics; persistence; resilience, etc.

Under pressures from conventional economic development, these qualities invariably have generally become compromised with both quantity and quality of ecosystem services diminishing. This occurs at a variety of scales --locally, regionally, and globally. Such declines in ecosystem services can prove catastrophic for the human community directly dependent on such services. A recent example is the collapse of the east coast ground fishery in Canada, with its high economic and social costs to the fishing villages and fish-processing industries that are the main-stay of the coastal economies.

Loss of Management Options

A second integrative measure of loss of ecosystem health is a decrease in management options. The impact of conventional economic development on ecosystems has in many cases resulted in a decline in potential uses of many kinds of natural resource systems. Regier & Baskerville (1986), for example, refer to the historical sequence of qualitative and quantitative resource changes after decades of cultural stress in the Great Lakes Fishery and in the New Brunswick forest under exploitative development. In both systems, over-exploitation of preferred species has entrained a process of 'Hygrading" -- harvesting less preferred species. Management options for the alternative use of the ecosystem (e.g., recreation, commercial harvests) have been sharply curtailed. Similar losses of management options have occurred with respect to overgrazing by cattle on western drylands.

In the case of impaired range lands, the carrying capacity of much of the land was reduced, and in extreme cases where the ecosystem was transformed from arid grasslands to desert, the options of using the ecosystem for grain or domestic herds was almost totally eliminated. Thus the loss of ecosystem health and integrity, needless to say, also invariably implies a significant loss in the potential uses being made of the system.

The loss of ecosystem services and management options reflect deterioration in ecosystem health. Here the metaphor with human health is apt. Often accompanying illness is physical or mental impairment or both -- resulting in less capabilities for coping. As illness progresses, generally speaking the rehabilitative options decline until the final stages of a terminal illness, when options for rehabilitation have disappeared and only palliative treatments may be given.

Economic Development and Environmental Change

A clear understanding of the general processes that link economic activity to ecosystem transformation and vice-versa is essential for formulating a comprehensive monitoring framework for indicators of sustainable development.

The key question becomes: What has been the associated spectrum of human activities which has led progressively to the decline of the viability of the earth's major ecosystems? Which activities have been directly associated with certain types of ecosystem damage? It is now possible to sketch out, in at least general terms, the sequence of events as environments become degraded under the pressure of economic and demographic change. Validating these general patterns might provide a basis for selecting a group of indictors that could be used to assess progress towards achieving 'sustainable development'.

Based on the classical work of Simon Kuznets -- see his series of papers in the mid-1960s in Economic Development and Cultural Change -- the general structural, economic, and social changes that have accompanied economic development are well established. It is clear that there has been a significant directional shift in the relevance of key economic sectors as economic development proceeds -- these patterns have been verified using both cross country data, and within country data.

In the early stages of economic development, the bulk of activity takes place in the agricultural sector and in harvesting natural resources. By far the greatest proportion of the labour force (over 90%) are engaged in agriculture. As economic development proceeds, one of the most striking patterns is the shift in activity: this proportion dwindles, so that the ratio ultimately is reversed, with 10% or less of the population engaged in agriculture, supporting the other 90%.

As agriculture falls in relative importance, there is a concurrent rise in the importance of industrial activity. At later stages of economic development, there is a further shift towards the service sectors. Throughout the development process, the importance of international trade and financial flows generally increases, although these aspects are also strongly impacted by the international political and economic climate. There have been periods of trade contraction, particularly during recessions and depressions reflecting the efforts of countries to keep what commercial activity exists within their boarders.

What are the implications of these economic patterns for ecosystem transformation? One may hypothesize the present environmental predicament has been the result of a series of waves of stress pressures corresponding to patterns of economic development, subsequently modified according to the changing technologies. Naturally there has also been some (relatively slight I would venture) effect from the adoption of so-called 'environmentally friendly technologies, and of various efforts to protect the environment by enacting legislation, international accords, protocols, etc.

Hypothesized patterns of ecosystem degradation and their interrelationship with stages of economic development are sketched in **Figure 2**. Naturally, the pattern of economic development has strong implications for the patterns of ecosystem degradation. Initial clearing of land for agriculture, and subsequent intensification of agriculture has had direct effects on loss of critical habitat and extirpation of small and large mammals. In some regions of Eastern Canada, more that 90% of natural wetlands have been drained for agriculture. Further intensification of agriculture has led to declining soil productivity (when the effects of subsidy are netted out), and in many areas, particularly with wide-row cropping practices, there has been pronounced soil erosion. These changes have led to increased farming pressures on more marginal lands, and declining quality and quantity of land and soil resource. In The Prairie and Parkland Belt (the northern fringe of the Prairie ecotone which is vegetatively dominated by aspen), a number of large and small mammals that were once common are now rare or extirpated. Among the large mammals now extirpated, one includes the Plains bison, Mountain sheep, Grizzly, Wolf (Canis lupus nubilis), Swift fox, Black-footed ferret, River otter, and Wolverine. Among the now rare species are Elk, Wolf (Canis lupus irremotus), Black bear and

Figure 2: Tracking the Development of Pathology in Global Ecosystems.

Progressive Marginalization of Resources ▸ Cascading ▸ Cumulative ▸ Global Impacts

Country *(are these the best delineations for study boundaries?)*	Stage of Development *(need classification schema/method of quantifying)*	Economic/ Population Indicators of Developmental Stage *(expect these to co-vary)*	Indicators of Resource Marginalization/ Degradation *(develop indicators for various media/ stages of development)*	Symptoms of Ecosystem Pathology *(others??)* ↓	Major Trends
South America	Primary Resource Use/ Extraction (forestry, fisheries, mining)	population density	over-harvesting?	loss of species and habitat/ deforestation/ fisheries??	↓ marginaliz. of land/soil resource
Africa	Agriculture	GNP	rate of land-use conversion	increase in rare and endangered species	↓↓ declining soil productivity
China	Urbanization	per capita income	irrigation/ soil salts/ fertilization	contamination of biota	↓↓↓ marginaliz. of water resource
North America	Services	quality of life index	water eutrophication	disease incidence (human and non-human)	↓↓↓ marginaliz. of air resource ↓
Europe	Industrialization	income distribution	water withdrawal	other indices of human health?	↓↓↓ marginaliz. of human resource?? ↓↓
	Technology (can it reverse trends)	imports + exports (connectivity)	water toxic contamination	loss of bio-diversity	↓↓↓ cascading/ cumulative impacts
		human development index (U.N.)	soil contamination	global climate change	↓↓↓ ↓↓↓ global implications
			air contamination	other intensifying global stresses (i.e. signs of cumulative global impact)	
			import of raw materials from other countries		
			waste production/export per capita		

Cougar. Among the small mammals that are now rare are: Red fox, Grey fox, Mink, badger, Raccoon, Bobcat, Lynx, Striped skunk, Prarie dog, Kangaroo rat, Bushy-tailed woodrat, Porcupine, Beaver, Franklin ground squirrel (Bird & Rapport, 1986).

Both industrialization and the growth of human settlements have benefited much from proximity to major water bodies --rivers, lakes, estuaries and coastal marine systems. Not surprisingly, then, next in the general sequence of degradation, is the marginalization of water resources. The most striking examples come from Northern and Eastern Europe: the Thames, the Rhine, the Vestula, have all been severely degraded by chemical contamination, nutrients, and physical restructuring. A similar fate has befallen many North American rivers (e.g., the Saint Lawrence, the Detroit, the Fraser, the Colorado). Declines in the health of river systems are often precursors to declines in the larger receiving waters. Most of the Great Lakes of the World as well as the enclosed or semi-enclosed seas have become significantly degraded -- this includes the largest inland freshwater bodies i.e.. the Laurentian Great Lakes and Lake Bikal, as well as sizable semi-enclosed seas (e.g. the Mediterranean, the Baltic) and major bays and estuaries (e.g. Chesapeake Bay).

As industrialization intensifies, air becomes the next resource to be marginalized. At the early stages of industrialization, air pollution is localized -- confined to the immediate environs of the factory stack. These local impacts may however be of devastating proportions -- e.g. the 'moonscape' produced by the smelters at Sudbury. Now a days there has been a remarkable and largely successful effort to stem these local blights on the landscape. However, one should recall that the "greening of industry" is largely a western phenomena, having little impact on the worst abuses of industrial production which predominate in much of the developing world (e.g., China, Eastern Europe).

As countries reach some intermediate stage of development (e.g. Mexico, Taiwan), diffuse sources of air pollution from the automobile and other transport vehicles extracts a toll on regional air quality. In urban areas, the daily cycle of 'dirty air' is well documented -- two of the best known examples being Los Angeles and Mexico City.

From an ecosystem health perspective, however, it is perhaps not the local effects, as visible and obvious as they are, which pose the greatest risk. More likely it is the global effects of a changing atmosphere, e.g. depletion of the ozone protective layer, increased concentration of so-called 'green-house' gasses. The local "hot spots" of severe air pollution retrospectively might be seen as early warning indicators of a global marginalization of air resources.

In the later stages of economic development, marginalization of the environment shifts from one's home turf to less fortunate countries -- that is, further deleterious environmental impacts tend to shift from the developed to developing countries. For example, the Japanese protect their remaining forests and trees (the Cherry tree is particularly sacred), while harvesting without much restraint the large tracts of South East Asian forests. North Americans are seeking agreements with developing countries for dumping of industrial wastes which are too costly, or prohibited from dumping at home, and industries are migrating from areas with restrictive environmental legislation to areas without such restrictions (so-called 'pollution havens').

Questions of Scale

Given the broad patterns sketched above, the question of appropriate scale for monitoring progress towards sustainable development needs to be addressed. Clearly the broad patterns suggest the proper scale is at least the large regional landscape, at the level of ecoregions or ecozones, or alternatively major drainage basins. International discussions on sustainable development and the various accords that support that goal are formulated on a national basis. Are nations the proper units for assessment of progress towards sustainable development, even though national boarders seldom respect ecological ones? From the ecosystem health perspective, it is clearly possible to functionally define smaller units (e.g. the Great Lakes Basin, the Boreal Forests, the Prairies) and evaluate these regions with respect to criteria for ecosystem health -- reflecting both the underlying organizational aspects of ecosystems and societal values. The size of the appropriate geographical units could vary from the large-scale ecosystem level to landscapes, nations and the entire biosphere.

Good.

When it comes to the landscape level, there are questions concerning the mosaic of ecosystems with differing degrees of pressure from human activity. Can a landscape be judged healthy and sustainable even though it contains elements which are clearly over-exploited? Or phrased slightly differently, what proportion of a landscape feature (say riparian zones) might become degraded while the landscape may be judged in good health? Naturally, these considerations suggest that the scale problem needs to be resolved before the indicator question can be properly addressed. Obviously, one needs to know not just what to measure, but over what domain the measurement makes sense.

Indicators of Ecologically Sustainable Development

Tracking progress towards the broad objectives of sustainable development requires first and foremost that the concept of sustainable development be sufficiently refined to be measurable. The concept itself is so all encompassing, that practically any data set could be said to have relevance! The challenge then is to select a small number of key indicators that collectively is of sufficient dimension to reflect the general tendency with respect to trends towards sustainable development.

I propose that, in fact, a small set of well-chosen indicators, provided they are adopted internationally, should suffice to reach sound conclusions regarding the 'not improbable futures' for particular regions and nations. These indicators ought to comprise, in most general terms:

Good.

(i) measures of the pressures on environment -- in terms of energy and material consumption, adjusted for economic structure, climate and other factors;

(ii) responses to these pressures in terms of the health of regional ecosystems and their susceptibilities; and

(iii) the potential for society to deal intelligently with surprise -- which relates to the knowledge base and its effective use in society.

In this paper I explore the first two of these three essential aspects of reporting on sustainable development.

(I) Indicators of stress pressure

Macro-level stress on the earth's ecosystems is a very complex phenomenon. It is known that many stress pressures can be transmitted long distances via atmospheric circulation, or can derive from transactions in the complex global market place -- this may also shift the 'source' of stress at a distance from where the actual impacts are felt. Further there is of course a potential sizable mitigating impact of technology. For example, the smelters at Sudbury have significantly reduced both the total discharge of acidic compounds (by installing pollution abatement technologies) and the local impacts of the discharge (by building taller stacks). Other factors influencing the impact of any activity include the degree of recycling in the production process, and the natural absorptive capacity of receiving environments, etc.

To evaluate direction of change, that is whether or not stress pressures are increasing or decreasing, a large number of measures may be appropriate -- each relating to specific classes of pressure, i.e. air pollution, physical restructuring (road network densities), energy generation (dams, size of dams, nuclear power generation) etc. However, by taking into account all such factors, one rapidly encounters 'data overload'. The alternative is to develop a small group of indicators that are highly correlated with trends in the multitude of specific stress indicators. A detailed study of stress pressures impacting Ontario eco-regions revealed that total population, population density, and energy use were highly correlated with all other more detailed measures of stress pressure and further, these measures were highly correlated with independently chosen biophysical indicators of the health of regional ecosystems (Rapport, 1994). These findings suggest that, although any number of macro indicators of stress measures might be chosen, very simple and readily available measures may serve as surrogates (at least for a first approximation) to measure overall stress pressures. In any event, the selected indicators ought to be utilized separately, and one should avoid the temptation to amalgamate them into a supra index, which tends to obfuscate information (Rapport & Regier, 1980).

A further complicating factor is the fact that industrialized countries are in a very different situation regarding the origin of stress pressures than less developed countries. In the former, stress derives largely from the economics of poverty, with minimal technologies; In the latter, stress derives from high levels of demand, high per capita use of resources and powerful technologies.

(II) Indicators of regional ecosystem health

Here again there is a plethora of key potential indicators of the health of regional ecosystems (e.g. Rapport, 1989a, 1989b, 1992a, 1992b; Rapport & Regier, 1994). Again, one seeks an sub set of indicators, which collectively is sufficient track the direction of change in the health of regional ecosystems.

As described above, a comprehensive approach to reporting and evaluating trends and conditions of the environment requires systematic tracking of stresses from human activity and extreme natural events, ecosystem responses to stress, and linkages between economy and environment.

The second component, that of ecosystem response to stress, is best evaluated within an ecohealth framework (Costanza et al, 1992). Since a primary objective in reporting on conditions and trends in the environment is to provide information which enables one to predict future states of the environment, it is important to take an explicitly diagnostic approach. That is, our goal ought not be to merely document environmental conditions and trends, but it should also be to predict future environments based on existing conditions and the modes of action of known stresses.

There are four key questions a framework for the response side should address: Is the state of the environment improving or degrading (General Screening)? If degradation or ecosystem pathology is found, what are the most probable causes -- taking into full account the ecosystem dynamics and lag effects (Diagnostics)? What changes may be expected in particular ecosystems in the near future, given present management practices and stresses from human activity (Risk Assessment)? How can we determine the 'healthiness' of an ecosystem, i.e. its capabilities rather than disabilities (Ecosystem Fitness)?

An ecohealth perspective provides the most suitable approach for tackling these questions (Costanza et al, 1992; Rapport & Schaeffer, 1992). This approach, while relatively new to ecology, draws upon a long history of development and practice in the health sciences. The connection to the health sciences gives the approach two additional advantages: (1) It is readily understood by the public, since practically everyone has had first hand experience in the four key aspects of screening, diagnosis, risk factors and fitness; (2) Many of its features have been tested for decades by the medical profession. Coupled with the fact that many aspects of ecosystem health are already embedded (some quite fortuitously) in present approaches to monitoring and reporting on the environment, the approach can be shown to be not only relevant, but also very practical.

(a) General Screening Indicators

The purpose of screening indicators is to identify those environments which show signs and symptoms of ecosystem pathology. In other words, general screening indicators are needed to distinguish, at a broad scale, those environments which are in various stages of degradation from those that are healthy -- or at least show no symptoms of breakdown.

Screening indicators are comprised of a number of generic classes which apply across the board to a large variety of ecosystems (Rapport et al, 1985). Ecosystem attributes, such as primary productivity, nutrient concentrations, biotic diversity, biotic composition, size and age distributions of dominant species, contaminant levels in biotic and abiotic components, have been shown to differentiate between stressed and unstressed ecosystems (Rapport et al, 1985). Accordingly, they have a rather solid scientific basis for use as general screening indicators of the health of most ecosystems. Naturally, however, the value of these parameters that differentiate between "healthy" and "unhealthy" states differs according to the particular environment. For example, in the naturally mesotrophic waters of the Lower Laurentian Great Lakes, the chlorophyll *a* concentrations are naturally higher than in the oligotrophic waters of the Upper Laurentian Great Lakes.

It is fine to emphasize that, however definitive a single parameter appears to be in particular circumstances, when distinguishing between stressed and unstressed ecosystems it is the entire set of symptoms of ecosystem distress that is required for a more confident assessment. Limiting the assessment to only one or two parameters can often produce very misleading results. For example, Schindler et al. (1985) showed that even after a considerable experimentally induced reduction in pH for small boreal lakes, primary productivity and nutrient recycling remained at near reference levels! However in this case, other features of the ecosystem distress syndrome, particularly changes in size distributions of biota and biotic composition, were very responsive to the lowering of pH. Thus for this example, reliance on a few indicators might have suggested that the system was 'healthy', while reliance on the set of general screening indicators would have shown definitively that the system was stressed.

Frequently asked is the question: "Is the state of health of the ecosystem independent of the indicators or are they one and the same?" If they are, then we have a classic case of circular reasoning. That is, if we are saying that the Lower Great Lakes are unhealthy because the measures of primary productivity, or nutrient concentrations, are in what we have defined as an unhealthy range, then we have circular reasoning. If on the other hand, we are suggesting from comparison with other similar type systems, that when the indicators collectively show a particular pattern, the ecosystem is severely stressed and it is well advanced along a path of degradation.

In the first case we assert the ecosystem is unhealthy because we have defined health by the very parameter(s) we are using for its measurement. In the second case, we assert that an ecosystem is unhealthy if it shows the same patterns characteristic of ecosystems well advanced in the process of degradation. In this case our indicators and health are not one and the same thing!

(b) Diagnostic Indicators

Diagnostic indicators, as the term suggests, have an entirely different function than general screening indicators. Their function is to identify causes, not to identify a system that is unhealthy. In other words, once an ecosystem is determined to be unhealthy, the question of "why?" arises naturally. For example, if there is an unusual amount of "die-back" within a forest, resulting in reduced productivity, the forest would be suspected of being unhealthy.

The next question is "why?" To 'rule-in' or 'rule-out' probable causes requires a different, more detailed set of observations. For example, is die back in a forest due to contaminants reaching the canopy and/ or soils? If so, a sensitive indicator might be the abundance of feather mosses, which are pollution intolerant. Other diagnostic indicators might include a soil profile for heavy metals, pH and the like. A further diagnostic indicator might lie in the sequence of die back -- where does die-back first appear in the tree and how does it proceed? (e.g. is it from the center outward, or does dieback first appear at the tree margins and move inward?) In the hands of a skilled practitioner, each diagnostic indicator helps to 'rule-in' or 'rule-out' possible causes of the overall pathology that was detectable from general screening indicators.

Here arises an important question of the proper levels of biological organization at which to monitor ecosystem health. Our preference is clearly aimed at holistic, systemic indicators of ecosystem structure and function such as productivity, nutrient cycling, and biotic composition. Most ecosystems are well buffered over time to normal perturbations so that long term changes in these parameters tend to signal fundamental restructuring. However because these parameters are robust, and because they are responsive to many types of stress they have high screening potential but low diagnostic potential (Rapport, 1990).

To increase the diagnostic potential, it is often necessary to choose indicators at lower than ecosystem levels of organization. For example, the appearance or disappearance of species particularly sensitive to specific stresses may have high diagnostic potential. Similarly, physiological levels relating to changes in enzymes within organisms, the appearance of tumors, etc. have been shown in various applications to have high diagnostic potential (Rapport, 1984; 1990). The important point is that indicators at different levels of biological organization have specific functions within the overall ecohealth framework.

(c) <u>Risk Factors</u>

Indicators of risk add an entirely different dimension to health assessments. While general screening indicators and diagnostics are designed to deal with existing processes of ecosystem breakdown, risk assessments focus on questions of potential hazards which may not yet be realized or reflected in the ecosystem's data.

How can one accomplish this?

Here is one of the best examples of the merits and limitations of the medical approach as applied to ecosystem health. In medicine, it is well established that certain habits pose a risk to life -- e.g., smoking, obesity, high-fat diets, etc. Through well developed methodologies it has been possible to quantify the risks to individuals for particular health problems (e.g., cardiovascular disease) from various factors. However to do this requires, in general, a large statistical base -- following the exposure and subsequent medical histories of thousands of individuals from a more or less homogeneous population.

Parallel opportunities rarely exist with respect to ecosystems and their exposures. However, in well studied pathologies, particularly involving exposure to acid precipitation and nutrient stress, it has been possible to quantify the relationships between exposure and ecosystem effects. For example, acidification has well known impacts on unbuffered lakes -- resulting in significant losses in biodiversity. Minns et al (1990) have used risk assessment techniques to predict losses in biodiversity in fish taxa in Eastern Canadian lakes. Through these techniques it is possible to evaluate the potential impacts of dominant stresses before symptoms of ecosystem pathology appear.

(d) Fitness

I use fitness here in the context of fitness medicine -- where the emphasis is on health prevention. This has no direct relationship to the evolutionary biologist concept of fitness, and the use of the same term in medicine and evolutionary biology may cause some confusion. However I would defend the use in this context as appropriate, for there is the need to test the "healthiness" of the system before it has lost its resilience.

Indicators of ecosystem fitness address the question of system capabilities, rather than system disabilities. Here again, a direct parallel is found with the health sciences. In fitness medicine, it is not disabilities, but capabilities that are measured. Capabilities and disabilities may well lie on opposite ends of the same scale. For example, in lung function, the loss of capabilities may become a disability -- normally some loss can take place, since for normal physical exercise, there is generally a surplus lung capacity. However, loss of capacity may foreshadow the development of impairments that become disabilities.

The application of these concepts to ecosystem monitoring is just beginning. The concept was only recently advanced (Rapport, 1992a; 1992b), and field testing will begin in 1994 on the Jornada Long Term Ecological Reearch Site (New Mexico). In these tests, arid grassland recovery from natural disturbance (mainly drought) will be monitored (retrospectively) through the use of remote sensing data and historical records. There will also be experimental tests using rain-out shelters. The hypothesis is that restoring primary productivity and community structure is slower and less complete in those systems that have been chronically stressed, for example by overgrazing, or by applications of herbicides. The measure of loss of capabilities would be the speed of recovery compared to the unstressed ecosystem.

Conclusion

Reporting on sustainable development ought to be based on an ecological perspective, within which questions of temporal and spatial scale are resolved and the concept of ecosystem health is given a primary focus. The large scale erosion of ecosystem health can be abated if the public is made more aware of the implications of present trends in the loss of ecosystem services and management options. Borrowing from methodologies developed in the health science, a systematic monitoring capability at the regional scale is possible, and four specific groups of indicators are recommended to serve various functions ranging from preventative health care to curative measures.

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