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Ecosystem services and management options as blanket indicators of ecosystem health

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Abstract

A pragmatic and integrative approach to evaluation of the environment combines ecosystem sciences, health sciences, and social sciences. Each has a crucial role to play: the ecosystem sciences provide information on the complex dynamics of ecosystems as they are influenced by stress and disturbance; the health sciences provide a methodology for systematic diagnosis of pathology, taxonomy of ills, and models for preventive as well as rehabilitative modes; the social sciences bring to the fore the importance of human values which are part and parcel of any health evaluation. The complexity of stress-response systems precludes anything approximating a complete understanding of mechanisms underpinning ecosystem transformations. However, the loss of ecosystem services and management options appears to be a general phenomenon that permits an overall evaluation of ecosystem health in both aquatic and terrestrial systems. Such blanket indicators take into account both the impairment of ecosystem function and societal values. This is illustrated by the history of ecosystem transformation in the Laurentian Lower Great Lakes and in the overharvested forest ecosystems of Eastern Canada. In both cases, cultural stress resulted in losses in highly valued ecosystem services and management options. These losses have been partially compensated for by new technologies that have permitted commercial use of the remaining lower quality resources. This process itself, however, may be pathological, reinforcing a degradation sequence rather than serving to restore ecosystem health.

1. Introduction

As evidence accumulates that many of the Earth's ecosystems have become severely damaged and that restoration will take decades if not centuries (Woodwell, 1994), the need for monitoring and assessing progress towards achieving ecosystem health has never been greater. Various approaches to the question of what constitutes ecosystem health (Rapport, 1989a; Rapport, 1992a, b, c; Rapport, 1995a, b; Rapport & Regier, 1995; Schaeffer *et al.*, 1988; Steedman & Regier, 1987; Kerr & Dickie, 1984) as well as means of detecting pathology (Hilden & Rapport, 1993; Rapport, 1983; Rapport, 1989b; Schaeffer *et al.*, 1988; Schaeffer & Cox, 1992) have been examined. Further, there is a vast literature accumulating on the complex dynamics of ecosystems under stress (Patten & Jorgensen, 1995; Rapport, Gaudet & Calow, 1995; Kay, 1991; Kay & Schneider, 1992; Allen, 1990). Some approaches are based on systems models (Levin, 1989), hierarchy theory (Allen, 1990), chaos, and thermodynamics (Kay, 1991; Schneider & Kay, 1995), and surprise (Holling, 1986). Other approaches are based on risk assessment (Suter, 1992; Minns *et al.*, 1990) and yet others are based on insights derived from case study methods (Schindler, 1987; Schindler, 1988; Hilden & Rapport, 1993).

These contributions have shown that (i) assessments of ecosystem health require simultaneous consideration of a number of dimensions including bio-physical, socio-economic, human health, and public policy (Rapport, 1995b); (ii) health assessments ought to be based on a suite of indicators rather than single measures (Odum, 1985; Rapport, Regier & Hutchinson, 1985); (iii) there are spatial and temporal lags and complex dynamics which relate stressors or pressures to effects or impacts on ecosystems (Hilden & Rapport, 1993), (iv) health assessments incorporate both bio-physical processes and societal values (Rapport, 1995b); and (v) the monitoring and evaluation of ecosystem health is now feasible for a number of large-scale ecosystems (Rapport, Gaudet & Calow, 1995).

Given the inherent complexity of assessing ecosystem health (both in terms of a wide variety of indicators which may serve one or more specialized functions, and in terms of the difficulty in separating signal from noise in a complex, evolving system characterized by novelty, inconsistency and surprise) (Funtowicz & Ravetz, 1994), and given the urgent need to make practical assessments in terms relevant to policy makers, one might wonder if there is any set of blanket indicators of health that in effect constitute a 'bottom line' in this type of assessment.

If there is a 'bottom line' to ecosystem health appraisals, it must satisfy two properties: (a) it should be related to ecosystem processes which are crucial for sustainability, and (b) it needs to be directly related to 'what matters' to society. In economic evaluations, the bottom line is profit or loss. What is the equivalent in ecosystem health evaluations?

Here one might seek a measure, or set of measures, that interfaces science and policy. The blanket indicators of health must necessarily speak both the language of the policy-maker, couched in terms of societal values (Norton & Ulanowicz, 1993; Lerner, 1990), and in terms of bio-physical processes (Patten & Jorgensen, 1995; Rapport, Gaudet & Calow, 1995). Environmental degradation is characterized by a progressive loss of ecosystem services (both quantitative and qualitative) and a loss of management options. As these losses meet both the criteria of being highly valued and serving as key functions necessary for sustainability, together they can serve as the bottom line of what the costs of environmental degradation are to society.

2. Pathology vs health

More than half a century ago, Aldo Leopold (1941) drew attention to the phenomena of failing or crippled ecosystems. He termed the condition 'land sickness', by which he meant ecosystems displaying a range of signs of pathology. These included soil erosion, loss of fertility, hydrological abnormalities, outbreak of pests and disease epidemics, occasional eruption of certain species, and mysterious local extinction of others. Leopold considered these signs of land sickness akin to medical signs of disease. At the same time, Leopold recognized that an environment free of 'land sickness' was not necessarily the same as one that is healthy. To be 'healthy', the ecosystem must not only be free of sickness, but should also be capable of providing services on a sustainable basis. Thus, health is not merely the absence of disabilities, it is the presence of capabilities (Rapport, 1992b). These capabilities may include the capacity for buffering perturbations, the capacity for progressive integration (Steedman & Regier, 1987), and the capacity for providing services on a sustained basis. Loss of ecosystem services and management options signals a loss of ecosystem capabilities and thus a decline in health.

3. Environmental assessment and health evaluations

With mounting environmental concerns, monitoring and assessing the condition of regional ecosystems is becoming a necessity (Rapport, Gaudet & Calow, 1995; Hartig & Thomas, 1988). While specific purposes for such undertakings vary, an underlying motive is to determine whether the ecosystem falls outside some bounds (limits) for 'acceptable condition'. If this turns out to be the case, many assessments attempt to determine some of the main causal factors, which, in effect, constitutes a defacto evaluation of ecosystem health, whether this term or others are used (e.g. ecosystem integrity, soil and water quality objectives, etc.). Health in its broad meaning in this context might be readily equated to a sustainable acceptable condition; one that neither diminishes the future evolutionary potential of the ecosystem nor diminishes the existing range of services and management options provided by the system.

By itself the designation of many of the bays and harbours in the Great Lakes as Regions of Concern, clearly indicates that not all ecosystems or subsystems pass the simple test of 'acceptability.' In these cases, the causes vary considerably from simple single stresses, such as excessive nutrient loading, to multiple stresses, as in Green Bay, where toxic substances, overharvesting, and physical restructuring have all played a role in the degradation of the system (Francis *et al.*, 1979; Hartig & Thomas, 1988; Fontaine & Stewart, 1990).

With respect to the Laurentian Great Lakes Areas of Concern, 'unacceptability', in most cases, translates readily to the loss of ecosystem services (Hartig & Thomas, 1988). For example, toxic substances in water, contamination of sediments, and fish consumption health advisories are obviously interrelated. The net impact of such conditions is to reduce ecosystem services in terms of amounts of fish of desired species and size classes which are safe to eat. Impairment of biota, particularly benthic invertebrate communities, may be a consequence of elevated phosphorus levels or discharge of organic material from certain industries, such as pulp and paper, or sewage. The impact here, too, is reflected in a loss of ecosystem services, in terms of water quality, preferred fish stocks, and recreational opportunities. In some cases elevated bacterial levels may be correlated with elevated phosphorus, and may pose additional public health risks if propagation and transmission of bacterial-borne infectious diseases are enhanced in eutrophicated waters.

Assessments on larger scales ranging from provinces or states to nations, groups of nations, and the entire world have been produced by various regional, national and international bodies over the last decade or so (e.g. Tolba *et al.*, 1992; OECD, 1993; Bird & Rapport, 1986). Such documents provide synoptic information on the state of environment for the public and decision makers. To these should be added numerous studies under the auspices of various regional commissions, for instance, those associated with the International Joint Commission on Boundary Waters (IJC), the Helsinki Commission, the International Council for the Exploration of the Sea (ICES), and case studies carried out by individual researchers (e.g. Rapport, 1983; Rapport 1989b; Hansson & Rudstam, 1990; Costanza & Greer, 1994; Admiraal *et al.*, 1993). All such studies have a broadly similar goal, to assess the condition of a regional ecosystem in terms of its viability. In one way or another, all these studies address directly or indirectly the extent to which the regional ecosystem is sustainable with present human use without impairment of underlying ecological functions. Thus, in essence, such studies are ecosystem health evaluations.

4. Health indicators: merging the objective and subjective

Despite the fact that evaluations of ecosystem conditions are now carried out commonly in many areas of the world, on both terrestrial and aquatic systems, some critics maintain that ecosystem health either cannot be brought down to concrete terms or is unworkable (e.g. Suter, 1993; Calow, 1992; Kelly & Harwell, 1989; Minns, 1992). If this argument were accepted at face value, that would render it difficult to undertake restoration of damaged ecosystems. Any restoration plan must have, at least implicitly, an evaluation of the failings or dysfunctional aspects of the existing system; i.e. a recognition of what has been lost (ecosystem function, services) as a first step to devising priorities for restoration.

In fact, any plans for ecosystem restoration or rehabilitation must identify what has been lost (often this is specified in terms of ecosystem services) and the goals and means of restoration. Such plans may state the objective in broad terms, such as restoration of the health or integrity of the system, or may refer to some particular criteria, standards, or guidelines to be met. Whatever form these statements take, they form judgment of the dysfunctional aspects of the system, which is predicated on some sort of health assessment.

Ecosystems may often exhibit alternative semi-stable states (Kay, 1991). Thus, what is healthy is not only what is sustainable, but also what is desirable, or, in other words, what is necessary to meet societal needs. Thus ecosystem health is inextricably bound in a social context, rendering it, in part, a matter of societal preferences. This introduces an element of subjectivity.

Ecosystem health is a normative concept, referring to a desirable, sustainable condition. What is considered healthy then amounts to a choice among alternative states within an envelope of all possible sustainable states. The envelope itself places the outer bounds on the range of possibilities, and provides an objective basis for health assessments. Clearly, healthy ecosystems need to be sustainable within ecological and evolutionary constraints which promote continuity and stability, while allowing for change and adaptation (Steedman & Regier, 1987).

Thus, necessary and sufficient conditions for maintaining ecosystem health lie in both bio-physical constraints and in societal preferences. Both aspects can, in part, be measured objectively (Woodley, Kay & Francis, 1993; Rapport, Gaudet & Calow, 1995). These necessary and sufficient conditions pertain as much to managed systems as to wild systems, with one important distinction; managed systems are sustained by continuous subsidy (as in aqua-culture, hatchery operations, agriculture). Therefore, the requirement for 'health' cannot, in these systems, be the absence of a subsidy, but rather the requirement that the subsidy is sustainable, i.e., not fossil fuel based. It is not uncommon for traditional practices in managed resource sectors to require continually increased subsidy, while also depleting natural capital (species and genetic diversity, soils, etc.). To restore health to these systems one must find methods that minimize subsidy, and adopt practices which avert damage to the system of focus as well as neighbouring ecosystems (Rapport, 1995b).

5. Mechanisms of change

While the consequences of ecosystem transformation, as will be argued, might be reflected ultimately by losses of valued ecosystem goods and services and losses of management options, these end-points are the result of complex dynamics at best only partially understood. Most systems are beset by a number of stress factors which, individually and collectively, impact the functioning of regional ecosystems. Generally, stresses operate synergistically, each enhancing the effects of the other, but occasionally they might offset one another. For example, nutrient loading tends to diminish the impact of heavy metals in boreal lakes (Rapport, Regier & Hutchinson, 1985).

A further complication is caused by the delays in propagation of stress effects, both temporally and spatially, and this 'latency' period may range from hours to centuries (Clark, 1986). An additional complication is that many stresses manifest similar sets of signs (Rapport, Regier & Hutchinson, 1985). This means that in specific cases, one often finds that cause-effect relations are so complex that they amount to not much more than conjecture. A recent interpretation of events leading to substantive restructuring of the Great Lakes fishery illustrates the nature of the complexity (Regier, 1995).

The main trends are clear enough, and so too are blanket indicators of health. What is unclear are the detailed mechanisms that caused these transformations, i.e. the relative role of various stresses (e.g. overharvesting, nutrient loading, toxic substances, physical restructuring, climate warming, introduction of exotics), and the pathways by which they led to changes in the fishery (Regier & Hartman, 1973; Rapport, 1983; Westman, 1990; Harris *et al.*, 1988; Regier & Baskerville, 1986). Regier (1995) offers a 'gross synthesis' of events, from which the following description of the complexities of the transformation in the Great Lakes borrows liberally.

According to this interpretation, each of the Great Lakes and Great Rivers consists of two holarchic subsystems or holons: a bowl-shaped holon comprising the riparian-littoral-benthic system of the bottom and its immediate overlaying water and a pelagic holon, which fits within this bowl and comprises the open waters, relatively isolated both dynamically and structurally from the substrate. The natural tendency of oligotrophic lakes is towards domination by the structurally better organized benthic holon. This holon which tends to be dominated by K selected species successfully competes with, and derives advantage from, the less organized pelagic holon.

The historical record suggests that 200 years ago, most significant elements of the Great Lakes Basin (the Lakes themselves as well as the Rivers, marshes and other aquatic subsystems) were dominated by a largely pristine benthic holon, perhaps similar in many respects to the remaining 'heritage areas' in the basin such as Long Point (Francis *et al.*, 1985). The cultural stresses of the past two centuries differentially impacted this dominant subsystem. While initially these stresses were of such a low intensity that they were absorbed and often neutralized by the benthic community of the lower tributaries, coastal zone, riparian edge, littoral benthic and profundal benthic zones, eventually the assimilative capacity of these communities was surpassed and the weakening of the benthic subsystem permitted an expansion of the pelagic.

Among the key stresses was phosphate loading, which continued to increase progressively as the benthic assimilative capacity was weakened. In shallow waters this led to anoxia in the hypolimnion, which in turn led to the demise of dominant biota of the oligotrophic benthic community. With conversion of inactivated phosphates into an active state there was reinforcement of the expansion of the pelagic system at the expense of the benthic. Further inroads to the benthic subsystem were made by shoreline restructuring, which removed much benthic habitat and created vertical slopes in place of natural gradual slopes. Offshore pelagic exotics, and accidentally and intentionally introduced species thrived. Both nearshore and offshore, the pelagic species (both fish and zooplankton) may have further suppressed the immature or young benthic species. Increased turbidity, resulting from nutrient enrichment, undoubtedly reduced the efficiency of sight-dependent benthic species that preyed upon pelagic species, thus further shifting the balance to the pelagic community. Overfishing reduced the last large benthic species in the oligotrophic parts of the lake (lake trout (*Salvelinus namaycush*) and ling (*Lota lota*)). Toxic contaminants may have also supported the pelagic community, since with shorter food chains, the toxic impacts were less in this community than in the benthic community where bioaccumulation reduced reproductive efficiency.

Thus, a wide variety of dominant stresses are implicated in the transformation of the Great Lakes ecosystem, and these collectively contributed to a progressively weakened benthic fish community, indirectly strengthening the now dominant pelagic fisheries. These new commercial fisheries are comprised partly of exotic fishes such as rainbow smelt (*Osmerus mordax*) and these have increased in their importance. In very recent years, there may have been reduction in the expansion of the dominance of the pelagic subsystem. In some areas such as the Bay of Quinte, with reduction of nutrient loading and reduction in loading of toxics by industry, a reversal is underway, strengthening the benthic community.

While a much clearer understanding of the forces shaping transformations in the Great Lakes ecosystem has emerged, it is clear the processes are so complex that a complete understanding of the various mechanisms at work, and their relative contributions, may never be possible. Fortunately, evaluations of ecosystem health do not depend on such an understanding. There are many examples in human health where diagnosis of pathology and evaluation of options for rehabilitation are made without a full understanding of the mechanisms responsible for dysfunction. Similarly, in the evaluation of ecosystems, the loss of services or management options, may be a sufficient basis for action even in the absence of detailed knowledge of all mechanisms responsible.

For example, in determining the effectiveness of various measures to reduce stress on the Great Lakes, one may rely on a variety of indicators including the composition of the biota, e.g. changes in the ratio of benthic to pelagic fishes. These indicators are pragmatic and may collectively be quite sensitive to both the degradation of the system and the beginnings of recovery which are now underway in some local areas (e.g. Bay of Quinte). Thus, evaluating health of ecosystems or humans, is not dependent on knowledge of precise mechanisms producing change, but rather what the changes mean in terms of human uses of the system. For this purpose, pragmatic measures, properly validated, can provide the decision maker a basis for action in terms of loss or gain of nature's services.

6. Assessing loss of ecosystem services

In the most inclusive sense, 'ecosystem services' can be defined as all functions performed by ecosystems, such as recycling of nutrients, sequestering of toxic substances, provision of renewable resources, shelter, and cultural identity. Any significant environmental change is likely to affect one or more of these services. Some transformations will degrade or eliminate services for which there are no close substitutes. The recent loss of the ground fish stocks off the east coast of Canada provides a current example.

An all-inclusive list of ecosystem services is not likely to provide much guidance in assessing ecosystem health, however a selective list of those services most highly-valued by the stakeholders, and at the same time those services which are judged essential to the maintenance (sustainability) of the system, provides one basis for an overall health assessment. Such a subset may include: wildlife diversity, the quality and quantity of harvestable renewable resources, including potable water, foodstuffs and fibre, carrying capacity for livestock, climate control, recreational activities, sequestering of contaminants, barriers to soil erosion, and biological controls for pest outbreaks. Even this list is by no means exhaustive.

Examples of the use of ecosystem services provided by Cairns & Pratt (1995) include the capability of ecosystems to cycle nutrients at the final stages of waste treatment processes whether from sewage plants or directly from septic systems. Local streams often perform the little appreciated function (service) of retaining eroded sediments, thus protecting downstream waters. Harvesting for food production includes the use made of native ecosystems, especially for fish. At regional scales ecosystems are exploited for fiber and fuel wood.

Westman provides a more specific example from the Great Lakes (1990) in his classification of the goods and services. Value 1 items comprise those aspects of direct benefit reflected in the marketplace. In the Great Lakes basin these would include the commercial value of sports and commercial fisheries, harvested crops, water (to the extent it is sold for drinking or irrigation), mining, shipping (to the extent fees are paid for the use of the lakes), and hydroelectric power. Value 2 items comprise various ecosystem products which have no commercial value, but are recognized as critical to the ecosystem. These include all flora and fauna which are not harvested, soils, wildlife habitat and the like. Finally, value 3 items include services of the ecosystem, for which Westman cites the example of 'radiation flux function' used by more than 30 thermoelectric power plants to cool their generators with lake water.

The history of degradation in most aquatic ecosystems is one of progressive loss of a number of these ecosystem services (Bird & Rapport, 1986; Government of Canada, 1991, esp., chpts 16, and 18–20). In practically all areas, it seems that the most valued uses are the first to go. For example, within the fisheries of the lower Great Lakes, the Atlantic salmon (*Salmo salar*) fell victim to the combined stress of damming, pollution, siltation of spawning habitat resulting from forest clearing, and over-fishing. Sturgeon (*Acipenser fulvescens*) declined owing to over-harvesting. The appearance of the sea lamprey (*Petromyzon marinus*) in the 1920s contributed to the decline of the lake trout in Lake Erie by the 1950's.

The net impact of multiple stresses on the lower Great Lakes has been a complete transformation of the fish community such that the most-valued species (e.g. lake sturgeon, lake whitefish, lake herring (*Coregonus artedii*) are reduced, while the less-valued and smaller forms, which are non-native to the Great Lakes, have thrived (Regier & Hartman, 1973). In this case, the loss of one of the 'ecosystem services', namely production of highly-valued species of fish, resulted in the provision of new services, namely the thriving pelagic fishery comprising rainbow smelt, alewife, and the Pacific salmon which feed on them. This pelagic dominated community, while recently less stable than earlier, represents a loss in ecosystem services from the point of view of highly-valued commercial and sports fisheries.

As in many cases where the loss of one opportunity creates another, the economy adjusts. For example, in Canada where both high quality fish and high quality forest resources were preferentially taken first, a process known as 'hygrading' occurred (Regier & Baskerville, 1986). As better quality resources were depleted, new uses were found for lower quality resources. This process partially compensated for economic losses from over-exploitation, but contributed further to the loss of ecosystem services, which could in these cases be measured directly in terms of valued species and size classes.

Adapting to lower-valued species and size classes occurred in the history of fish exploitation within the Great Lakes. Here the process of making do with less-valued stocks and adapting economically to the over-exploited resource is termed 'fishing-up'. Fishermen in the Great Lakes were able to add to the economic value of ecosystem services of diminished quality by processes such as salting, refrigeration, freezing, filleting, smoking, precooking, etc. For example, the parallel to plywood and chipboard projects (below) may be frozen fish (Regier & Baskerville, 1986, p. 87). Further, with over-exploitation of the most accessible fishes, which tended to be nearshore benthic species, labour-intensive commercial and sports fisheries diminished and capital-intensive offshore enterprises developed.

An historical overview of changes in the forests of New Brunswick provides another example of the progressive losses in quality and quantity of preferred species. In the New Brunswick forests, harvesting in the early 1800's was selective for the valued white pine (up to 300 years old) for ship masts. When the white pine became scarce due to over-harvesting, the sawmill industry which emerged in the mid-1800's shifted to the larger white spruce, and later to balsam fir. Currently the minimal acceptable size for all these species is but a fraction of what it was a century ago. Further the technologies in the lumbering industry adapted to lower quality and quantity of woods, so that less-valued species, smaller trees and stems of lower quality found uses in the manufacture of laminated beams, plywood, chipboard, and so on (Regier & Baskerville, 1986, p. 80). A similar history is found in the pulp and paper industry, where the utilization of whole stands shifted over time to those of smaller stem size which could sustain higher volumes per year, requiring new technologies to utilize them.

Losses in the quantity and/or quality of highly-valued species characterizes many ecosystem transformations under stress from human activity. In some cases, a partial restoration of services has been achieved by human interventions. But the results achieved from such interventions seldom compensate fully for the losses in ecosystem services. For example, historically the Laurentian Lower Great Lakes comprised mesotrophic or oligotrophic waters where native species provided both a thriving commercial and sports fishery. Today many of these opportunities are lost, and the sports fishery of Lake Ontario is largely maintained by artificially stocking an exotic species (Pacific salmon) which, owing to bioaccumulation of contaminants, is not recommended for human consumption.

It is difficult to value quantitatively the net effect of stress on the gains and losses of ecosystem services. It is hardly possible, for example, to aggregate the value of all ecosystem services lost and gained and thereby arrive at a net cost. Attempts to do this by applying Cost Benefit Analysis (Westman, 1985, 1990) show that results are highly dependent on methods employed in making the calculations, e.g. by estimating (i) the damage costs: that is, the economic costs of the loss of ecosystem services; (ii) the repair costs: that is, the costs to bring back the lost services, for example the costs of reintroduction of salmon and trout and the costs of restoring the appropriate water quality to support these species; and (iii) the costs of replacing the lost functions by alternative means. Each of these methods has limitations and all give rather different estimates. All these calculations at best capture only part of the true costs of ecosystem degradation, for there are a number of non-market values accompanying these changes in dominant species. For example, there are very different nutrient cycling processes associated with benthic driven vs pelagic driven systems. The indirect effects of these have wide-ranging implications, from the quality of recreational opportunities to the increased risk for transmission of certain classes of pathogens through eutrophicated waters.

While some decision makers might claim that 'if this cannot be brought down to monetary terms, they are unable to act', this is at variance with the fact that decisions in many areas of human endeavour are not dependent on reducing all factors to monetary costs and benefits. Included here are decisions on social justice, human rights, military alliances and so on. The preservation and restoration of ecosystem health would easily fall into this broad class of decisions, which are clearly in the social interest, but not compressible into monetary terms. The consequences of sustained cultural stress on ecosystems are a progressive loss in ecosystem services. Furthermore erosion in ecosystem services will increasingly place the viability of these systems, and the human societies they support, at risk.

7. Management options

A healthy ecosystem is supportive of many uses, and through management these uses can be altered from time to time to adapt to changing market conditions. For example, arid grasslands might serve as recreational lands, as grazing lands for domestic livestock and large game, as natural areas for the preservation of bio-diversity, and as a vegetative buffer regulating runoff to drainage systems (Whitford, 1995). With overgrazing and irrigation, severe erosion and salinization problems have developed in may arid regions. These changes have resulted in reduced carrying capacity for cattle, loss of wildlife, and declines in water quality. In consequence, management options for land use have been correspondingly diminished (Milton *et al.*, 1994).

Eutrophication in the Lower Great Lakes also provides an excellent example. With eutrophication up to the mid 1970s, has come reduction in sports and commercial fishing opportunities and consequently a reduction in recreational opportunities. The viable uses of the lakes and bays were severely curtailed, for some time, although some recovery appears to be underway (Whillans, 1979).

The adaptive response to the loss in management options has been to create new ones making use of lower quality resources. The concept of 'hygrading' is well illustrated in the Great Lakes Basin. In Southern Ontario, for example, the option for growth of commercial timber has long been lost, as lands that once bore hefty stands of white pine are no longer even classified as productive forest! In other areas of eastern Canada, timber production for building supplies has all but disappeared, and what remains are lower grade species which find use in production of pulp and paper (Regier & Baskerville, 1986). In the Great Lakes, the abundance of exotic pelagic species, particularly rainbow smelt and alewife, gave a temporary boost to a fish-meal industry, which, of course, only partially compensated for the options lost in commercial fisheries for the most highly-valued species.

8. A new 'bottom line' for gauging human activity

The fact that ecosystem services may decline linearly with declines in ecosystem health (Cairns, Jr. & Pratt, 1995), suggests they are a good integrative and aggregate measure of ecosystem health. The summary of degradation in the Great Lakes suggests that simple measures, such as the loss in quality of the fishery (for example the shifting benthic/pelagic ratio), are adequate to simplify the situation for purposes of presenting information to the interested public as to the consequences of these changes (Rapport, 1983).

The first line of analysis for new projects ought to be: what will this project mean in terms of lost ecosystem functions and products, and lost management options? If there are significant losses that cannot be fully compensated by replacement of the services and options, then the project should simply not be considered further. Situations that degrade health are simply not to be tolerated. It is only the second tier of decision making that should then consider the actual costs/benefits of developing the project, in the conventional sense. Projects promoting ecosystem health need to pass both tests!

9. Discussion

Unfortunately, 'bottom line' indicators such as ecosystem services and management options usually register far too late in the sequence of events leading to ecosystem breakdown to be of use as early warning, and clearly only serve as 'risk' indicators by demonstrating what services and functions may have already been lost, and by extension, what may be at risk. Neither are losses of ecosystem services and management options likely to be of much use as 'diagnostic' indicators. As has been shown often, the loss of particular services, for instance preferred fish stocks in the Great Lakes, is due to multiple causes. Different ecosystem ills appear to lead to the same end-points (Rapport & Regier, 1995). Bottom line indicators serve primarily in assessments of overall ecosystem health condition (general screening and state of environment reporting) and as goal-setting instruments in policies designed to protect or enhance ecosystem health.

Both ecosystem services and the recognition of management options are necessarily highly dependent on societal values. However, as the case record shows, stressed ecosystems show progressive losses in both camps. They go hand in hand; the loss of services means the loss of options. The compensation by economic substitutions, while attempting to minimize losses in economic activity owing to failing ecosystems, may in effect be sowing the seeds for longer term degradation of ecosystem health, as these economic processes tend to reinforce the degradation sequence rather than correct it. Concerted efforts to restore ecosystem health regionally and globally require a well defined set of ecosystem attributes that can be readily translated into overall health and viability of these complex systems.

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