ECOSYSTEM HEALTH: DEFINITIONS, ASSESSMENT, AND CASE STUDIES

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Summary

The degradation of the Earth's ecosystems entails a loss of life support for all organisms including the human community. Regaining the health of the Earth's ecosystems is emerging as a major societal goal. Vigor (productivity), organization, and resilience, in terms of both biophysical functions and socioeconomic aspects characterize healthy ecosystems. The biophysical realm takes into account consideration of climate, atmospheric chemistry, energy, materials, food, soil fertility, etc. The socioeconomic aspects include sustaining economic activity, social services, and human health. The latter is particularly at risk in developing countries and in urban areas not only from pollution but also from ecological imbalances that have been the source of many emerging diseases and the resurgence of old diseases. Ecosystem health rightly becomes

an important topic in human and veterinary medical programs as illustrated by the revision of the curriculum of a major medical school. The relations of human activity, threats to ecosystem health, loss of ecosystem services, and consequences and challenges for viable human futures are illustrated by two case studies: one focusing on desertification; the other on dryland salinity.

1. Introduction: The Biosphere in Distress

Ecosystems breakdown with attendant loss of both ecological structure and function has become pandemic and has inflicted a rising toll measured in broad-scale change and human misery. At the global scale, this is measured in terms of thinning of the ozone layer, rising levels of CO_2 concentrations in the atmosphere, net loss of tropical and temperate forests, net loss of arable land, and decreasing supplies of potable water. It is also recorded in terms of non-sustainable forestry, agriculture, fisheries, newly emerging diseases and the resurgence of old diseases, and social and economic decline, particularly in rural areas.

When, some 60 years ago, Aldo Leopold introduced the concept of "land sickness," it was already evident in the landscape of his native Wisconsin. Today, it is rampant in the landscapes around the world, and both causes and consequences are far better understood. The situation has sparked societal response at all political levels from the local to the global. As a consequence there are innumerable international treaties, agreements, protocols, and regional and local "action plans" to improve the situation. In some cases, with respect to certain specific issues (for example, the reestablishment of fish in the River Thames in London, England; reduction of nutrient loading in the Laurentian Great Lakes; reduction of air pollution in some urban areas) there have been positive changes. However, in many cases the problems are multiplying faster than the solutions, and according to a recent global assessment by the United Nations Environment Program, *Global Environment Outlook 2000*, the tendency towards ecosystem degradation, at the regional and global level, is not only continuing, but probably accelerating.

Never before in human history has the Earth's ecosystems and its biosphere been so severely compromised as today. Uncontrolled, unwise, and unsustainable demands on the planet's life support system severely threaten the future viability of humankind. A collision course between economic and population growth and the carrying capacity of the planet appear imminent. Manifestations of this are already evident in some regions of the planet. Once-fertile lands in North Africa, in China, and in North America, for example, have been transformed, largely through over-grazing, to deserts, supporting a tiny fraction of the productivity and biodiversity that once prevailed. Tropical rainforests, hotspots of biodiversity, continue to disappear owing to clearing for agriculture, and over-harvesting. Coastal marine ecosystems in many regions have become polluted. Pollution (mainly through nutrient runoff) of the coastal zone, coupled with over-harvesting of marine commercial fisheries and habitat loss is responsible for the decline in many of the world's key commercial marine fisheries. Urban air quality has become so compromised that respiratory disease in the human population is common in many urban areas.

All the above are signs of failing ecosystem health. Unless the health of the Earth's ecosystems is restored, it will become increasingly difficult to project whether or not the human population can be sustained, and current and projected levels of human sustainability in the twenty-first century will become increasingly at risk. Furthermore, while it is often claimed that technology can compensate for the destruction of the environment, there is scant evidence that this has been the case, particularly at the regional scale. Indeed, there are numerous examples where attempts to mitigate the failing of ecosystem health have simply transferred the problem elsewhere. For example, fertilizers are routinely applied to compensate for declines in soil fertility, in order to maintain crop yields. However, these interventions have resulted in side-effects such as contamination of ground water, streams, lakes, and estuaries, negatively impacting wildlife, fisheries, and human health. For example, nutrient-enriched coastal marine waters have been shown to enhance the growth of *Vibrio cholerae* the pathogen responsible for cholera outbreaks.

Clearly, one of the prerequisites to a viable human future is restoring and maintaining healthy ecosystems. In this article the concept of ecosystem health is articulated from biophysical, socioeconomic, and human health perspectives. Assessments of ecosystem health must be carried out within the complex dynamic that interrelates these elements. Both qualitative and quantitative indicators of ecosystem health are being developed for each of these dimensions, and some of the concepts being employed, e.g., resilience and organization, cut across the different aspects. Interrelationships between the socioeconomic, biophysical, and human health aspects are emphasized throughout, and particularly within the two concluding case studies.

2. What is Ecosystem Health?

Ask a dozen experts what constitutes health in humans and there are likely to be 12 different answers—or perhaps no answer at all. The reason for this is that most medical practitioners focus on pathology (illness), not health. Their responsibility has by and large been to treat the disease, not to promote health. A similar focus prevails when it comes to questions of ecosystem health.

Definitions of ecosystem health are thus often couched in terms of the absence of signs of pathology, rather than in terms of signs of health. A lake, for example, is deemed "healthy" if it shows none of the obvious signs of pathology such as contamination, algal blooms, loss of fish species, and the like. Focusing on health, per se, brings into play an entirely different set of criteria. In broad-brush terms, ecosystem health may be defined as the capacity for maintaining biological and social organization, on the one hand, and the ability to achieve reasonable and sustainable human goals on the other. From this perspective ecosystem health is as much about sustaining human communities, economic opportunity, and human and animal health, as it is about sustaining the biological functions of ecosystems.

Looking further into the properties of ecosystem health, three major attributes have been identified: vigor (productivity), organization (including the diversity of biota and their interactions), and resilience. Vigor or productivity refers to the capacity of the system to sustain the growth and reproduction of both plants and animals. Organization refers to

the capacity of the system to support a diversity of lifeforms and their interactions. Resilience refers to the capacity of the system to buffer perturbations; that is, the capacity to rebound after disturbances such as fire, floods, windstorms, and the like. While these attributes have been best worked out in terms of the biophysical properties of ecosystems (that is, from ecological perspectives), the concepts also apply to the socioeconomic and human health dimensions of ecosystem health. For example, in a healthy ecosystem, economic activity is buffered against the vagaries of market forces, for the system can support a variety of alternative human activities that can be brought into play to maintain a source of incomes for the human communities within the system.

As ecosystems include the human communities, the evolving definitions of ecosystem health encompass the direct implications of biophysical changes (described above) on humans. That is, there are direct social, economic, and human health consequences associated with ecosystem health. The economic manifestations of ecosystem health are sustainability livelihoods (with both rural and urban components). The human health manifestations are clearly seen in the vigor of the human community that is part of a particular environment. Epidemiological studies suggest that, increasingly, human ills are being driven by environmental decline. For example, cholera, malaria, Dengue fever, Ross River virus, Lyme disease, cyrptosporidosis, to name a few, are all enhanced by degraded environments.

How do healthy ecosystems become unhealthy or pathological? The transformation of ecosystems from healthy to unhealthy states is readily explained by the cumulative impacts of chronic stress from human activities. Major sources of stress include: the release of waste residuals (e.g. release of contaminants to air, water, and land); over-harvesting and the physical restructuring of both terrestrial and aquatic ecosystems (e.g., dams, water diversions, roads, and utility corridors which fragment the landscape); and the introduction (purposefully or accidentally) of exotics (species not native to the ecosystem). Additional stress comes from climate change and depletion of the protective stratospheric ozone layer.

The cumulative effects of acute and chronic stress result in ecosystem distress syndrome (EDS). Key signs of EDS include: enhanced volatility of fluctuations in component population numbers, reductions in biodiversity, simplification of food webs through elimination of key species, relative depletion of the larger and longer-lived biotic components, declining yields or harvests, increasing disease prevalence (within both plant and animal species), and increases in dominance by exotic species. In addition, most terrestrial ecosystems (e.g. forests, grasslands), as damaged systems, show reduced secondary productivity and altered rates of nutrient cycling. These changes, in turn, result in impairment of ecosystem services (e.g. potable water, and supplies of renewable resources, flood protection, and pollinator activity).

Ecosystem health concerns itself with the relationships between biophysical changes, disease burdens on the human community (and other biota, including both plants and animals), and the social structure and economic sustainability of human communities. This is a difficult area in which partial understanding as a result of “single focus” models is giving way to a holistic perspective, characterized by interactions between the social, economic, ecological, and public health dimensions, uncertainty of outcomes,

and surprise. The key goals of ecosystem health assessment are to elucidate the nature of these interactions, and to provide a set of indicators (drawn from all of the relevant domains) for the diagnosis of ecosystem pathology. Through this process, it should be possible to detect, at an early stage, deterioration in ecosystem health, and thus identify opportunities for recovering health while it is still possible to reverse damage at a reasonable cost.

The next three sections describe the biophsyical, socioeconomic, and human health dimensions of ecosystem health in more detail. A section follows on quantitative methods for characterizing ecosystem health at regional (landscape) scales. The two case studies illustrate the "bricks and mortar" of an ecosystem health assessment. The article concludes with a section on the prospect for restoring health to the Earth's ecosystems.

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