The Use of Resource Inventories for the Evaluation of Threats to Ecosystems and Protection of the Environment

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Abstract.—Strategies for the use of resource inventories for the preservation of threatened ecosystems include classification and characterization of critical ecological components, and the evaluation of the nature of threats to these systems. Currently, resource inventories are being conducted at different levels of effort for a variety of reasons, including lists of species from biological surveys and determination of the geographical extension of significant associations of plants and animals, evaluation of populations of species that constitute important resources, such as timber surveys, evaluation of grassland communities for grazing, and stock assessment of commercially important fish.

Methods of analysis of risk due to contamination by toxic chemicals have been developed using laboratory toxicity tests. Nevertheless, these tests are not able to make accurate predictions at the level of community or ecosystem. Moreover, other anthropogenic factors such as changes in land use, destruction of habitat, introduction of exotic species, and changes in climate that threaten entire ecosystems are not predicted by traditional techniques of toxicological risk assessment.

The concept of ecological risk analysis is based on two premises: 1) it is impossible to prevent all the environmental effects due to development, and 2) the management and protection of natural resources is necessarily based on incomplete scientific information. A method to develop ecological risk analysis using resource inventories consists first in defining ecological health in terms of sustainability, and defining critical attributes at the level of community and ecosystem in order to maintain ecosystem health. Examples of these attributes includes the dynamics of critical nutrients and energy, trophic structure, biodiversity, condition and genotypic diversity of key species, patterns of dispersion and migration, and stage of ecological succession. Secondly, these critical ecological attributes should be amenable to analysis in relation to the sensitivity of the ecosystem to expected anthropogenic stress and comprised of specific selected parameters on a regional basis for monitoring. The maximum and minimum tolerable values for each index monitored should be determined to provide a diagnostic capacity and predict various levels of stress to the ecosystem. Finally, measurement endpoints should be formulated into a monitoring program that would allow timely evaluation of the status of ecological resources.

INTRODUCTION

At present, regions where development is accelerating encounter serious problems that affect the quality of the environment and the status of natural resources. These problems include large scale changes in land use, contamination of entire aquatic and terrestrial ecosystems, regional contamination of the air, coastal degradation, loss of wetlands, introduction of exotic species, loss of biodiversity, and climatic

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changes induced by man. All these problems cause the degradation of the environment over a long time period and at a large scale. Ecosystems of great value such as large lakes, deep rivers, estuaries, and even entire biogeographic regions are being subjected to multiple anthropogenic perturbations. The effective management of natural resources over long time periods and at large scale requires new strategies for the evaluation and integrated monitoring of the environment (Odum, 1993).

This paper provides a general strategy for ecological risk analysis using resource inventories and categorizes the type of information necessary to provide critical knowledge over an ecological data base that allows evaluation of the impact in the early stages of anticipated development. This strategy supposes that ecologists understand, at least in principle, the ecological basis of support for natural resources and the importance for application of ecological principles for managing these resources. Some forms of regional economic development are inevitable. Nevertheless development should not take place at the expense of existing natural resources. Evaluation of threats to ecosystems and their resources should be part of the process of planning for those in charge of regional development and managers of resources.

RISK ANALYSIS

Analysis of risk in the medical sciences has concentrated in the past on factors that directly affect human health and mortality. For example one can calculate the risk due to cigarettes, the use of certain medicines, or the construction of nuclear power plants. In the field of environmental sciences, risk analysis has been applied to the use of pesticides and the discharge of industrial chemicals based on calculations of the fate of these chemicals in the environment and batteries of laboratory toxicity tests in order to estimate the effects of chemicals on important representative species (USEPA, 1992). These methods of evaluation, however, are not able to calculate the indirect effects on other organisms, the effects at higher levels of organization, such as community or ecosystem, and are not able to estimate the effects on non-chemical stress and the impacts of multiple chemical effects (Bartell et al, 1992).

Ecological risk analysis supposes that, 1) the elimination of all effects of development is impossible, and 2) the management and protection of natural resources is made on the basis of incomplete scientific information (Suter, 1993). The stratagem elaborated here would extend and incorporate information derived from resource inventories into a risk analysis scheme in order to identify changes before damage has occurred at a large scale. The information would be used to predict the final changes and to plan for mitigation of potential ecological damage. This type of evaluation is retrospective and retroactive in the sense that it appraises changes that have already occurred; however, it is also prospective and proactive in that it uses estimates of change in the early steps of degradation and ecological knowledge from the inventory in order to estimate the final stage of a resource or ecosystem due to the impact of development. The condition of the resource or ecosystem due to the impact is the point of departure for this analysis.

INVENTORIES AND RISK ANALYSIS

Natural resource inventories in the past have dealt with making catalogues of existing species and establishing the limits of their geographic distribution (Kim and Knutson, 1986), and the assessment of items of major resource value, such as the volume of wood in timber surveys (Lund, 1986), evaluation of the condition of grassland communities for grazing (Breckinridge et al, 1995), or assessment of the stock or number of fish (Charles, 1994). However, these inventories are also able to provide critical elements in a program of risk analysis if they include an ecological perspective and entail the following steps:

1) Definition of ecological health;
2) Characterization of regional profiles of ecological health in terms of critical ecological attributes, and
3) The formation of ecological end points that can be measured in order to determine the health of the ecosystem and provide a basis for monitoring.

Ecological Health

The health of an ecosystem can be characterized considering the age or stage in succession of the ecosystem (Odum, 1969). Ecosystems in the early stages of succession will have different characteristics and greater susceptibility to threats than those more mature. In practice, the concept of health of an

ecosystem should include determination of keystone species and critical communities, and not the evaluation of an overwhelming number of species (Cairns, et al, 1993; Nip and Udo de Haes, 1995). This will require knowledge of the local or regional ecology, critical judgement, and prioritization by ecologists conducting the inventories.

Characterization of the concept of ecological health should be derived from knowledge of ecological theory and should include an array of physical, chemical, and biological attributes directly responsible for the existence and sustainability of the ecosystem (Shaeffer et al 1988). The physical availability of habitat is a necessary precursor for the presence and survival of organisms. There certain critical minimum requirements of habitat for many species or communities below which they are not able to exist. For example, if wetlands are drained or destroyed, there can be no wetland species or communities. Certain forms of energy such as adequate sunlight, various forms of chemical energy, physical energy such as wind or water currents, are also critical for the existence of certain organisms. Over all, large scale changes in land use, for example forest or wetland to agriculture, are so destructive of habitat that minimum requirements of species or communities should be determined scientifically.

Chemical characteristics of ecosystem health include adequate inorganic nutrients to maintain the biological community. These nutrients include, not only those commonly associated with primary productivity, but those required by animal nutrition as well. Moreover, not only the presence of adequate amounts is important, but their cycling through the system and biological availability as well.

Biological qualities indicative of ecosystem health include: 1) genotypic and phenotypic diversity adequate to sustain and perpetuate organisms, 2) a robust food web to maintain the structure of the community, 3) feedback mechanisms to reduce disruptive oscillations, 4) the ability to either decompose toxic chemicals or to bind them so that they remain unavailable to biological organisms, and 5) the degree of functional redundancy of a system (Barnthouse et al, 1991).

These physical, chemical, and biological characteristics should be evaluated to characterize the vulnerability of different types of ecosystems to various forms of stress. The ability to metabolize toxic chemicals is due to a range of physical, chemical, and biological characteristics characteristic of various types of ecosystems. This ability imparts a certain ecological inertia to stress (Westman, 1978) that is important in the evaluation of risk. The functional redundancy of an ecosystem implies a number of species present that are able to perform the same tasks within the system. For example, there may be a number of species that feed in a like manner (e.g. herbivores, carnivores, detritivores) that can replace one another functionally if one species is unable to function due to stress. Mature, complex ecosystems with a high degree of functional redundancy are ecosystems with inertia or a resistance to stress that would severely impact other simpler ecosystems (Odum, 1969).

Regional Profiles of Ecological Health

In defining ecological health on a regional basis, an analogy to characterizing human health is useful. Human health may be defined as the condition of the body as determined by a number of parameters such as body temperature and structural integrity, height-weight relationship, the chemical condition of blood and other body fluids that are parameters of the biological condition of various organ systems, etc. Measurements of these critical health attributes within certain ranges are considered healthy. When these limits are exceeded the individual is considered diseased or unhealthy, and some sort of medical action is warranted.

In order to use ecological theory to expand the interpretability and use of resource inventories it is useful to introduce the term ecological paradigm, which is defined as a specific model or set of hypothesis encompassing comprehensive characterization of resources at the population, community, or ecosystem level of organization. Ecological theory provides the basis for management, diagnosis and treatment of the ecosystem in the same fashion the human anatomy and physiology provides the basis for the practice of human medicine. The selection and application of the ecological paradigm depends on the management questions asked in planning the inventory. For example, single species populations routinely inventoried include major resource organisms such as commercially important fisheries or trees valued for timber, pest species, important charismatic megafauna, or endangered species. There are ecologically interpretable population models that incorporate reproduction, growth, and survival; life tables in the form of

Leslie matrix; analysis of population structure (ie size, age, sex); and assessments of the importance of interrelations with other species (i.e., predation, competition, parasitism, mutualism, etc.).

Inventories at the community level are commonly done to classify forest types, to conduct vegetation analysis, to identify baseline data to establish biogeographic regions, and to asses environmental impact. Community level ecological paradigms include successional models and the establishment of criteria for climax communities, various types of community structural analysis such as diversity, dominance, similarity, stability, measurement of primary or secondary production or yield, and various aspect of biogeography such as immigration/extinction ratios and species equilibrium.

Examples of paradigms at the ecosystem level are the River Continuum Concept (RCC) (Vannote et al, 1980) which describes how physical, chemical, and biological conditions change as a small streams become larger and larger eventually becoming a large river. Important aspects of the RCC include watershed area and hydrological discharge, functional group analysis (feeding guilds) of fish and benthic invertebrates whose ecological role changes with changes in stream size, changes in the pattern and importance of detrital organic carbon, the relative role of photosynthesis and the periphyton/phytoplankton communities, nutrient loss, and discontinuity within the longitudinal ecological succession of a river due to anthropomorphic disruption.

Inventories of lake ecosystems can be facilitated by considering the trophic succession model (oligotrophic, mesotrophic, eutrophic, or hypertrophic), limiting nutrient, nutrient loading chemical classification, and by key physical attributes such as depth, volume, surface area, dynamics of mixing, formation and depth of thermocline (Wetzel, 1982).

The use of regional frameworks is important in the subdivision of broad geographical efforts in both management of natural resources and environmental protection. (Gallant et al, 1989; Omernik and Griffith, 1991)). An explicit geographical framework for assigning critical ecological characteristics within regions to determine ecological health has been proposed by Omernick (1987). Certain limits of these ecological characteristics within defined ecological regions should have certain expected limits that can be used for regional risk analysis (Grahm et al, 1991; Hunsaker et al , 1990). The organization of resource inventories into regional patterns would yield a data base that could be used to define the bounds of selected ecological variables to determine ecological health.

Ecological Enpoints

In a fashion similar to human medicine approaches, sets of ecological endpoints should be formulated from the formal theory in ecological paradigms. An ecological endpoint is defined as an ecological parameter whose normal operating limits can be determined for the ecosystem in question (Suter 1990). A major effort in ecosystem risk analysis is the identification of appropriate ecological endpoints that are indicators of ecological health and sensitive to early stages of anthropomorphic change. In order to relate to human society these ecological endpoints should be associated with social, cultural, or economic consequences. For example, the uncontrolled development of mining may damage water quality which will cause a loss of a commercial fishery. The application or excessive use of certain types of pesticides may cause the extinction of charismatic megafauna of national importance. From an operational aspect, ecological endpoints should be easily measured, quantifiable, and amenable to statistical analysis. They should be sensitive to early or defined status of ecological stress to allow for mitigation measures to be employed.

Examples of endpoints include quantitative estimates of density of commercially important species or charismatic megafauna, the status of an introduced pest species on a large scale, changes in the concentration of critical nutrients (either additions or losses), especially those nutrients such as nitrogen and phosphorus known to control primary production, and measure of community structure such as density, species richness, diversity, similarity, and dominance.

Ecological endpoints can be arranged in profiles to characterize and monitor through time the ecological health of the resource and ecosystem in question. Some research in determining appropriate ecological endpoints, statistical properties, and required measurement frequency are necessary.

SUMMARY

The model that is proposed here for the development and use of resources inventories is presently in use for aquatic natural resources in National Parks in the United States (Boyle et al, 1991). Attributes of these programs may find applicability other areas and countries. Eugene Odum (1975) has characterized ecology as the bridge between the social and environmental sciences. The form in which environmental data will be used determines how the data will be collected. How the inventories are used depends on the system of values of the country and the region, its economic situation, its customs, practices, and laws. What is important is the formulation of a strategy that is appropriate and a program of collection of data on resource inventories that has broad ecological applications for the management of resources and the protection of the ecosystem.

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