ENVIRONMENTAL VARIABILITY AND INDICATORS: A FEW OBSERVATIONS[1]

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Abstract. *The environment of the earth is exceedingly complex and variable. Indicator species are used to reduce that complexity and variability to a level that can be more easily understood. In recent years, use of indicators has increased dramatically. For the Forest Service, as an example, regulations that interpret the National Forest Management Act require the use of indicator species for monitoring the effects of management actions. Although indicators have been in use for a relatively long period of time and such use is increasing, there are a number of problems associated with the use of indicators that need to be examined. These problems include selection criteria that preclude selection of useful indicators; lack of knowledge about what environmental characteristics, if any, they indicate; and selection of single indicators to monitor complex problems. Given the problems associated with the application of the environmental indicator concept, do indicators have a role to play in the management of forests and other systems? Use of indicators can substantially reduce the complexity and costs of collecting information and monitoring. They also reduce the complexity of environmental issues to a level that can be more easily understood by resource decision-makers and the general public.*

Introduction

An indicator is a component of a system whose characteristics (presence or absence, quantity, distribution) are used as an index of those attributes that are too difficult, inconvenient or expensive to measure for other conditions of interest (Landres *et al.*, 1988). The indicator concept has been used to assess various environmental conditions for decades. One of the earliest applications of indicators was the use of canaries to assess the presence of methane gas in coal mines. If the birds showed signs of distress, miners evacuated the workings. More recently, nitrogen oxides have been used as indicators of air quality; temperature, pH, and oxygen concentrations have been used as indicators of water quality; and both animals and plants have been used as indicators of various aspects of environmental quality.

Although indicators have a relatively long history of use, they often have been applied improperly and a number of problems associated with their use have been identified. This paper will briefly review the diversity and complexity of ecosystems, discuss why indicators are useful and advantages and disadvantages of their use, and suggest ways to make the concept more useful.

Diversity

The earth is extremely complex and variable and in a constant state of change. There are a multitude of factors that characterize a geographic location and influence the organisms living there. These factors include geological characteristics, latitude, slope, aspect, temperatures, precipitation, and many more. The flora and fauna at any place on earth are exceedingly diverse. By some counts, there are at least 350,000 plant (Bold, 1967), 900,000 insect, 30,000 protozoan, 104,000 mollusk (Vaughan, 1972), and 41,000 vertebrate species existing somewhere on earth; not to mention the myriad of species that do not belong to these groups. Of the vertebrates, there are some 20,000 (Romer, 1959) to 25,000 fish (Storer, 1951), 3,100 amphibian, 5,100 reptile (Porter, 1972), 8,700 bird (Welty, 1975), and 4,100 mammal species (Vaughan, 1972). These numbers are constantly changing as our understanding of the world's flora and fauna improves and as speciation and extinction add or subtract species.

Northwestern California is among the most diverse regions on earth. Relatively steep mountains with canyons, proximity to the Pacific Ocean, variable rainfall within and between years, and other abiotic factors produce a setting with a great number of potential habitats for plants and animals. Biotic diversity is high. As an example, some 400 or approximately 62% of the resident or regularly migrant terrestrial vertebrate species in California can be found in Northwestern California.

Variability in Space and Time

Not only are there immense arrays of different geographic situations and species on the earth, but the combinations of situations and species vary greatly across space and time. Different arrays of physical factors produce a mosaic of combinations of plants and animals over the landscape. However, those physical and biotic elements of a landscape are not static; rather they are constantly changing in response to natural events and human activities that may occur periodically or sporadically.

Perhaps a good example of the variance of a component of the system through space and time is the behavior of the snag (dead trees) population. Snags—and the logs that

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result from snags falling—are important to a variety of forest species and to the process of recycling organic matter. Although a background level of tree mortality occurs at a relatively constant rate in many systems, large numbers of snags often develop in pulses responding to droughts and other environmental factors. The geographic and temporal patterns of these pulses of mortality often appear as groups of dead trees scattered across the landscape and through time. As time progresses, snags are reduced to logs in frequencies related to snag species and diameters.

The suitability of snags as habitat for specific uses also varies. Certain snags are more desirable as sites for nests of cavity nesting birds than are other snags. Some of the variables that may related to use by cavity nesting birds are diameter, height, length of time since death occurred, time of year that death occurred, cause of death, species of rots, pattern of rot, and undoubtedly others.

Scale in Space and Time

The combinations of plants and animals existing on a landscape vary continually over space and time because of factors such as weather, changes in reproductive success, and exploitation of previously uninhabited sites. Characteristics of these combinations vary considerably depending on the scale at which they are viewed.

As scale increases in space and time, diversity also increases because a greater proportion of the land or time base is being viewed, variation in the landscape generally increases, and the number of species increases. As the scale decreases, diversity also generally decreases.

Changes in the Landscape Through Time

The landscape is continually changing, sometimes subtly and at other times obviously. Both physical and biological processes are continually in operation resulting in changes to the shape and constituents of the landscape. Vegetation assemblages proceed through successional processes and animal associates respond to the changes in plant species composition and structures (Oliver and Larson, 1990). Disturbance and recovery of biotic components are parts of the natural process. Both can be induced by various means including fire, flood, wind, and landslides. Disturbances are variable in geographic space as well as in intensity, and are reflected in composition of the flora and fauna and the speed in recovery.

Human actions and inactions also cause changes in the structure and composition of ecosystems. Actions such as timber harvest, urban development, and other intensive uses of the land can cause relatively long lasting changes in ecosystem characteristics. Other actions, such as fire suppression, have substantially changed the character of the landscape. The results of natural processes and human activities are ecosystems more complex than we think and they may be more complex than we can think (Thomas, 1991).

Responses to changes in the landscape vary depending on the plants and animals occupying the site and the kind and intensity of the disturbance. The response of a forest to disturbances such as a light ground fire, intense crown fire, wind throw, and landslides will be markedly different from place to place because of the biotic and abiotic constituents of the site.

Indicators

Indicators can be used to reduce environmental complexity to a level that can be understood. Applying indicators to real-world problems may or may not be an appropriate action depending on the question being asked. A number of recent publications (Landres *et al.*, 1988; Noss, 1990) have extensively discussed the indicator concept; the following is a brief summary of the uses of indicators and their advantages and disadvantages.

Use Of Indicators

Users of the indicator concept have defined indicators in a variety of ways. National Forests, as an example, are required to identify a group of "Management Indicator Species" (MIS). MIS are to include those species identified by state or federal governments as rare or endangered, those of social or economic value, those identified by the Forest Service as having habitat requirements especially sensitive to management actions, and species that can be used to monitor changes in the environment. Species selected only because they are rare or endangered, or have social or economic value may only be indicators of themselves and not good indicators of ecosystem health or of the needs of other species. Indicators chosen because they have habitat requirements that are sensitive to management or because they can monitor changes in the environment might well be more appropriate to indicate effects of management activities on the forested ecosystem and its inhabitants.

Modern assessments of environmental quality and effects of resource management often use indicators; they are perceived to be adequate for assessing changes resulting from management actions. Wildlife status is often evaluated using population density estimates of an indicator species as an index of habitat quality. It is assumed that responses of populations of other species using that habitat are similar to the indicator. As an example, habitat quality for species such as spotted owl (*Strix occidentalis*) and fisher (*Martes pennanti*) is often evaluated to indicate the quality of habitat for other species that are found in older, closed canopy forests.

Perhaps the best reason for using indicators is that they are cost-effective. Collecting information on indicators is often much cheaper and faster than using alternative approaches to evaluate changes in the environment.

Problems With Indicators

Although indicators have long been used for environmental assessments, until recently, the validity of their use has not been well evaluated. There are a number of problems with using indicators of any sort. The greatest, of course, is using measurements of any single attribute, or even several, to assess the quality of a complex and variable system. Indeed, this approach can show how well the indicator is responding relative to how one thinks it should be responding, but it is questionable whether measuring a few values can properly evaluate the health of a system.

Using numbers of a species as an indication of the health of a system is also not reliable (Van Horne, 1983). If human population density were used as an indication of the highest quality human habitat, then densely populated urban areas would be interpreted as the highest quality habitats for humans. There are other variables that also influence population densities and if they are not understood, erroneous conclusions could be drawn from such assessments. Using animal numbers to indicate system health may be erroneous because censuses may be done at a time of year that is not appropriate (Van Horne, 1983). Densities may reflect past, or short-term rather than long term quality, and social interactions may cause large numbers of "surplus" individuals to collect in "sinks".

It is rarely known if an indicator is capable of effectively reflecting the health of the system. Often indicators are selected without a great deal of consideration of how many, if any, other characteristics of the system are indicated by it or how well the indicator performs. In addition, the models used to assess quality are often not sufficiently tested or not tested at the appropriate scale. Unfortunately, because little work has been done to quantify the effectiveness of indicators and approaches used to interpret that assessment, absolute reliance on indicators is not a sound policy.

Improving Indicators

Several ways have been proposed to improve the effectiveness of indicators (Landres *et al.*, 1988): 1) clearly state the goals of the assessment including the criteria for determining when the goals have been achieved; 2) use indicators when appropriate and necessary; and 3) choose indicators using appropriate criteria that are explicit.

Stating the goals of any assessment and the criteria for determining when goals have been achieved is an essential, but often neglected, part of using indicators. Identification of the assessment goals can be used to judge whether or not the selected indicator is appropriate for the task. Vertebrates are often used as indicators of various environmental systems. Vertebrates, however, are relatively long-lived and the actual causes of perceived declines are often difficult to unravel. Specific migratory birds on first glance could be considered as good indicators of riparian and forest systems. However, because they are migratory, perceived declines may be the result of changes within their breeding range or wintering range, stopping places during migration, or post-breeding areas. Such species can definitely suggest that a problem is occurring but may be of little help in identifying where it is occurring or the cause of the decline.

Broad level assessments, such as for the general health of a system, may well be more appropriately evaluated using indicators that are geographically specific, respond quickly to change, and are responsive to the ultimate causal factors that are changing. If one is proposing to assess the health of a forest, it may be more appropriate to use a hierarchical approach, as advocated by Noss (1990), to ensure that system is evaluated at different functional scales. In addition, using species associated with soil productivity—*e.g.*, mycorrhizal fungi, other soil microorganisms—should more quickly detect those effects that may be fundamental to the functioning of the system. Use of such indicators may also provide information on other components of the ecosystem. As an example, recent work indicates that fungi, including mycorrhizal fungi, are important components in the diets of small mammals (*e.g.*, Maser *et al.*, 1978; Li *et al.*, 1986; Maser and Maser, 1988a, 1988b; Maser *et al.*, 1988; Blaschke and Baumler, 1989; Calvo *et al.*, 1989). Because small mammals are important diet components of carnivorous species such as hawks, owls, and mustelids, using fungi as indicators may also provide useful information on these upper level carnivores.

If assessments of changes in indicators are to be based on field data, as opposed to models operating on information such as remotely-sensed vegetation data, then the methods used may be suitable for gathering information on additional species, thereby increasing the indicator information collected with little or no additional expense. As an example, it makes little sense to choose a passerine bird as an indicator and then collect field information only on a single species. Sampling the passerine bird community would cost little more and yield more responses to the shifting environment. Perhaps one should view indicators from the perspective of the methods used to evaluate changes in them. If the same methods are useful for a number of species, it would be desirable to collect information on all of the species.

Conclusions

The environment of Northern California is complex and variable, and the resulting plant and animal assemblage is accordingly quite diverse. Indicators are often used to assess changes in the biota that are thought to be responses to human caused changes in the landscape. Indicators have a number of significant problems associated with their application. These problems can be largely overcome by setting clear goals, ensuring that the indicators do indeed meet the intended goal, approaching the analysis from an hierarchical perspective to evaluate the system at different scales, and selecting indicators that are more directly influenced by the changes in the environment and, therefore, more quickly respond to environmental changes. Using indicators is generally very cost effective compared to measuring, at appropriate intervals, all of the components of the system. Indicators are, therefore, a useful tool when applied in an appropriate manner.

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