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A Conceptual Basis for an Index of Forest Integrity for Upland Coastal Plain Ecosystems

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Abstract

Following the recent trend to manage natural resources for "sustainability," ecologists, resource managers and policy-makers are beginning to think of the management of forest ecosystems in terms of "ecosystem health" or "ecosystem integrity." Biologists are increasingly recognizing that use of chemical assays in assessing the condition of an ecosystem has limited value, and that biological factors, e.g., species diversity and composition, can be useful characters in the analysis of "biotic integrity." An index of biotic integrity (IBI) has been developed for riverine ecosystems in the Midwest U.S., using fish species diversity, indicator population analysis, trophic structure assessment, and physiological abnormalities in fish as measurable surrogates for "biotic integrity". This paper explores the development of an analogous index of forest integrity (IFI) to be applied to the upland coastal plain forests of southern Arkansas and northern Louisiana. The IFI developed here includes sampling and analysis of population trends of dominant plant taxa, plant species diversity, and horizontal and vertical vegetative structure at midstory, shrub and detritus levels.

Introduction

The term *biotic integrity* was coined by Karr (1981) in a paper concerning the monitoring of stream ecosystems in Illinois. Karr reasoned that the use of biological parameters is a more proximal and, therefore, more accurate approach to understanding biological systems than the use of chemical assays. His fish monitoring system was intended to quickly and accurately assess the "health" of riverine ecosystems, thereby superseding the use of water chemistry measures as ecosystem health monitoring tools. The system is based on seven measures of diversity and five measures of population and guild structures (Table 1).

Table 1. Parameters for Aquatic Index of Biotic Integrity. After Karr (1981).

Species composition and richness	Population and guild analysis
Number of species	Number of individuals per sample
Presence of tolerant species	Proportion of omnivores
Richness and composition of darters	Proportion of insectivorous cyprinids (carp and minnows)
Richness and composition of suckers	Proportion of top carnivores
Richness and composition of sunfish (except green sunfish)	Proportion of abnormal individuals (e.g., disease, tumors)
Proportion of green sunfish	
Proportion of hybrid individuals	

Karr termed his system an index of biotic integrity (IBI). Its utility lies in its simplicity and cost-effectiveness, as the necessary field data can be collected from a site in one or two days of field work with basic equipment. Subsequent to Karr's work in Illinois, it has been used to assess the environmental quality of streams in Wisconsin (Lyons, 1992) and Ohio (Gatz and Hartig, 1993).

The IBI does not transfer readily to terrestrial ecosystems, because trophic structures are not as readily distinguished and assessed, and because the trapping of mammals, insects and herpetofauna, and the censuring of birds are far more time-consuming and costly than the capture and release of fish. The study of metabolic processes (e.g., analysis of nutrient budgets, analysis of productivity and respiration rates, and energy flows) might provide significant insight into the "integrity" of an ecosystem, but like animal population studies, those studies are also expensive and complex.

Recognizing the practical and budgetary limits posed by zoological and ecosystem-level studies, and the conceptual limitations associated with the use of abiotic factors as indicators of integrity, we began to look for other, more easily-obtained biological metrics that might serve as surrogates for zoological and ecosystem balance characters. We determined that plant species composition and structure, which is known to define habitat for animal species (Webb, 1948; MacArthur and MacArthur, 1961; Otte, 1976), can be used to characterize the completeness and level of forest ecosystem functionality, and are there-

by a suitable basis for assessing forest integrity. We have termed our approach an index of forest integrity (IFI).

Discussion

The integrity of very small forest stands is dependent upon size. They lack the coolest and most humid regions; they have lower species richness; their reproductive processes are higher risk and they are more likely to be adversely disturbed by humans than larger areas. Edge effect creates an environment different from forest interior. Edge effect can be detected up to 100 m toward the interior of an ecotone (i.e., forest boundary) for plants (Matlack, 1994) and up to 200 m toward the interior for birds (Cieslak, 1994). This limits the utility of community diversity analysis in stands smaller than 20 ha, depending on the shape of the stand. Each taxon has its unique sensitivity to habitat boundary.

Landscape-level analysis (e.g., > 500 ha or 1000 ha) is often hampered by disjunctive land ownership, natural patchiness, and fragmentation caused by farms, highways and other developments. At the landscape scale, natural β diversity (between stands) patchiness begins to confound α diversity (within-stand) analysis.

A stand (or habitat or site) is often somewhere in between these sizes. The IFI is designed to assess stands (or habitats or sites) within this size range that are relatively homogeneous in vegetative association. From a practical standpoint, forests often manage compartments of 20 to 50 ha, so this is a useful scale for analysis. Larger areas might also be evaluated if natural patchiness and land use histories do not prevent it. In stands several hundred hectares or larger, β diversity begins to dominate over α diversity (within stand), and the evaluation would be modified accordingly.

The IFI assesses sites in relation to two conditions. First, it is compared with the plant community composition before industrial forestry began making major modifications to the Gulf Western Coastal Plain [See Galatowitsch (1990) and Cornett (1994) for methods. Foti and Glenn (1991) have also used this technique in the Ouachita Mountains]. This composition is derived from tree species and density data from 1830s land surveys that are available at each county's courthouse and at the State Land Commissioner's Office.

The second condition against which the IFI can be held is an "optimally managed" forest stand. We are soliciting consensus (via mail poll) about the meaning of "forest integrity" from scientists, policymakers, hunters/fishers, wildlife managers, foresters, forest land owners, and environmentalists. The model for forest integrity based on forest management concerns will be constructed with the results of that poll.

In development of the ecology-based IFI model, we evaluate three areas of vegetative diversity and forest physical structure (Table 2): 1) population dynamics of dominant tree species; 2) α diversity of trees, shrubs and herbaceous vascular plants; and 3) physical vegetative structure of the stand (e.g., canopy cover; shrub, mid-story, and canopy densities; leaf area indices; and vertical and horizontal vegetative profiles).

Table 2. Parameters for index of forest integrity.

Population dynamics	α diversity and similarity indices	Vegetative structure
dominant tree species	woody species	leaf area index
co-dominant tree species	vascular herbaceous species	ground cover
pioneer tree species	test site/natural site comparisons	canopy cover
	test site/desired site comparisons	vertical profile

The decline of dominant species is sometimes a sign of a community in transition, and is often an indication of disturbance. In managed forest stands, dominant species can decline because of overharvesting of marketable species, or because inadequate regeneration was in place before harvest was undertaken. More generally, population declines occur when a community is subjected to stresses that change the balance of resource availability among existing species, and which allow new opportunities for opportunistic or pioneer species. Tree species provide habitat and physical structure for birds, insects and small mammals, they alter the thermal regime through direct shading and evapotranspiration; they create significant amounts of detritus which is vital to ground insects and they provide food resources for many taxa of forest inhabitants. Accordingly, the integrity of the forest is closely associated with the vigor of tree population structures.

Because every site has a unique level of maximum species diversity, the question of whether a site is represented by a full complement of species that might "naturally occur" is a difficult one. In reality, practically all sites have been compromised in this regard, so the theoretical maximum species diversity for a site is not of practical importance. Therefore, existing diversity (at all levels) is interpreted as a fraction of a theoretical maximum. High species diversity corresponds with completeness, and lower species diversity corresponds with missing components. Low diversity also suggests reduced redundancy, which can limit the ecosystem's functionality.

Over the past century, many measures have been developed to assess species diversity (Baev and Penev, 1993). Most indices of species diversity evaluate some aspect of evenness (dominance), or richness (total number of species) or both of these. The IFI uses several

indices which evaluate evenness, dominance and similarity between sites.

Vegetative, dead wood and detrital structure have long been recognized as key factors in determining the number of niches in a habitat, and therefore the extent of species diversity at the habitat or stand level. In particular, more physical complexity has been correlated with larger deer populations (Webb, 1948), higher bird diversity (MacArthur and MacArthur, 1961; Whittaker, 1970), higher gastropod diversity (Kohn and Leviten, 1976), and higher orthopteran diversity (Otte, 1976). Field methods of determining and quantifying the complexity and patchiness of vegetation have been available for over a half century (Wight, 1939). MacArthur and MacArthur (1961) and Nudds (1977) further refined techniques for using a "density board" or "vegetation profile board" to assess physical vegetative structure. The IFI uses density board readings at several horizontal distances and heights through the understory and midstory. Volumes of dead wood and detritus are observed. These structural measures provide a surrogate for insect and small mammal habitat quality.

The IFI described here is an attempt to assess habitat, population, and community viability, through the simple and inexpensive measurement of vegetative parameters. Field data are being collected in the 1995 field season. Analysis of these data will determine which of the factors discussed above are the most robust, and how they must be weighted in order to best distinguish among sites of varying integrity.

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