Indicator species analysis: an alternative approach to ecosystems geography

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Abstract: Ecosystems geography, or ecogeographic analysis, is the study of the distribution, pattern, structure, and identification of ecosystem boundaries at different levels of detail. Ecological regionalization frameworks are becoming increasingly popular as a logical means of spatially organizing the landscape for the conservation of natural resources, management of the environment, and analysis of spatially distributed ecological phenomena.

The objective of this research was to utilize the cartographic modeling, image analysis, and processing capabilities of geographic information systems (GIS) and remote sensing to conduct and ecogeographic analysis of the state of Indiana utilizing readily available ecological data. The purpose id to demonstrate the use of these technologies in the field of ecosystems geography and compare the resulting regionalization schemes with those developed through traditional methods of ecological regionalization; specifically those of Lindsey (1969) and Homoya et al. (1985).

Two alternative methods of ecogeographic analysis, referred to as indicator species analysis and multivariate cluster analysis, were evaluated. This paper focuses on the application of indicator species analysis, the calculation of an indicator species diversity index, and generation of an indicator species diversity surface in order to delineate ecological boundaries and convey information regarding the the breadth and magnitude of change between adjacent ecosystems. It is suggested that such methodologies may provide resource managers and researchers with a means of defining regionalization frameworks for the management, conservation, and analysis of spatially distributed ecological phenomena that are tailored to the specific management or research initiative at hand.

Introduction

An increasingly popular application of regional systems is their use as a tool for the conservation, management, and analysis of spatially distributed ecological phenomena. Traditionally, government and private concerns have utilised political units as a template for the management, administration, and analysis of the environment and natural resources. Whereas this may be appropriate for infrastructures established within this context, it is surely an illogical approach for the management of naturally occurring systems. Recently, there has been an increasing awareness and interest in the distribution, pattern, structure, and identification of ecosystem boundaries at different scales of analysis, commonly referred to as ecosystems geography or ecogeographic analysis (Bailey 1996). Many government agencies have begun to develop management strategies based on the regionalization of natural areas or ecosystems for management, assessment, and reporting (Gallant et al. 1989).

The delineation of ecological regions is susceptible to common problems associated with the regionalization process. The boundaries of regions are often assumed to have determinable limits where the characteristics of one region are suddenly replaced by those of an adjacent region. However, few anthropogenic and likely fewer natural regions have hard boundaries. More often, the distinguishing characteristics of adjacent regions gradually change from one region to the next and specific values are chosen to define the boundaries between regions. These intermediate areas or transition zones are referred to as ecotones. An ecotone may be defined as the intersection between adjacent ecological systems having a unique set of biotic and abiotic characteristics described in terms of space, time, and the strength of interaction between adjacent ecological systems (Holland 1988). The delineation of hard boundaries, however, fails to express the breadth and magnitude of change between adjacent regions. Further, landscape boundaries defined in this manner do not indicate the strength of interaction between adjacent ecosystems and potentially valuable information is lost.

Existing ecological regionalization schemes (e.g. Bailey 1976; Omernik 1987) developed for specific applications are likely inappropriate for the variety of conservation, management, and analysis initiatives currently under consideration; particularly at regional or finer scales of analysis. Current ecogeographic literature supports the development of hierarchical, multipurpose regionalization schemes utilising the gestalt, map overlay, or controlling factors methods (Bailey 1996). These methods result in regionalization schemes that are intended to satisfy a variety of applications at various scales of ecological analysis. However, these approaches are essentially a form of manual cartographic analysis and tend to be labour intensive, inherently subjective, and impossible to replicate. Provincial, State, and local ecological regionalization schemes are often based on the expertise of key individuals having an intimate knowledge of the local ecology; an admittedly effective technique but highly subjective and lacking any structured methodology.

It is proposed that alternative methods of ecogeographic analysis utilising the cartographic modelling and image analysis capabilities of geographic information systems (GIS), remote sensing, and readily available ecological data may provide comparable results in a structured, efficient, and cost effective manner. Such methodologies would provide resource managers and researchers with a means of developing custom or user defined ecological regionalization schemes tailored to the specific management issue or research initiative at hand.

The objective of this research was to use the cartographic modelling, image analysis, and processing capabilities of GIS and remote sensing to conduct an ecogeographic analysis of the state of Indiana using readily available ecological criteria. The purpose was to demonstrate the use of these technologies in the field of ecosystems geography and compare the resulting regionalization schemes with existing natural divisions of the state developed through traditional methods of ecological regionalization; specifically those of Lindsey et al. (1969) and Homoya et al. (1985). Further, an alternative approach to the delineation and cartographic presentation of ecosystem boundaries is presented which provides a means of conveying information concerning the breadth and magnitude of change between adjacent ecological systems through the generation of an ecological surface.

Two alternative methods of ecological regionalization were examined. One was based on the spatial distribution of biotic criteria and referred to as indicator species analysis; and the other based on the distribution of a selection of abiotic components of the environment and incorporating multivariate cluster analysis. This paper describes the methods and results of indicator species analysis.

Methodology

Indicator Species Analysis:

This method of ecological regionalization identifies boundaries through the development of broad vegetative regions based on the distribution of indicator species (Livingston 1903; Clements 1905; Curtis 1959; Dix and Smeins 1967). Indicator species are defined here as those species that reach the extent of their geographic distribution within the state of Indiana and, consequently, the limit of their geographic range represents a potential landscape boundary. Indicator species analysis was originally proposed by Livingston (1903) and Clements (1905) and was used by Curtis (1959) to identify floristic provinces in Wisconsin. The premise of this approach is that the distribution of species typical of a particular ecological region is a more useful indicator for determining ecological boundaries than the distribution of rare species. An assumption of this approach is that ecoregion boundaries or ecotones represent a zone of maximum regional indicator species diversity. In other words, ecotones are areas where a number of indicator species representative of adjacent ecoregions overlap. Curtis used distribution maps for 180 species to identify the zone of maximum regional indicator species diversity, or ecotone, between two floristic provinces in Wisconsin.

GIS Development:

A GIS vector coverage was created in Arc/Info depicting the total number of indicator species, number of indicator species representing each ecological system, and number of ecological systems occurring in each county for the state of Indiana. These data were recorded as point attributes located at the geographic centre of each county.

Indicator species were selected with reference to Parker (1936) and Freisner (1937). These authors have identifed over 150 trees, shrubs, herbs, flowering plants, ferns, and aquatic species that reach the limits of their range within the state of Indiana. These indicator species are representative of five broad ecological regions: 1) Northern Coniferous Forest; 2) Tall Grass Prairie; 3) Atlantic Coastal Plain; 4) Appalachian Plateau; and 5) Gulf Coastal Plain. The geographic distribution of 120 indicator species was determined using Deam's Trees of Indiana (1921) and Flora of Indiana (1970) as well as current distribution maps of the trees of Indiana developed by Jackson (1997).

Ecological boundaries were identified by mapping the distribution of indicator species representative of each of the five ecological systems occurring in the state. Boundaries were determined by generating isolines depicting the distribution of Atlantic, Appalachian, Northern, Prairie, and Southern species. Isarithmic maps were generated by first interpolating a lattice from the county based points coverage based on the number of species within each system occurring in that county. Three interpolation methods available within Arc/Info were considered: 1) kriging; 2) trend surface analysis; and 3) inverse distance weighting (IDW). Of the three, only the IDW method provided reasonable results and allowed the resulting lattice to be extrapolated beyond the extent of the input points coverage to the edge of the state boundary. Kriging provided reasonable results but did not allow for extrapolation and trend surface analysis resulted in unacceptable results since there was less than a critical number of points in the input coverage.

Isolines were then generated using the Arc lattice-contour function. Figure 1 illustrates the resulting isolines draped over a choropleth map showing relative indicator species abundance; similar maps were generated for each of the five ecological systems considered. The distribution of ecological systems was defined by the isoline representing one third of the total number of indicator species occurring in that system. It was reasoned that areas having

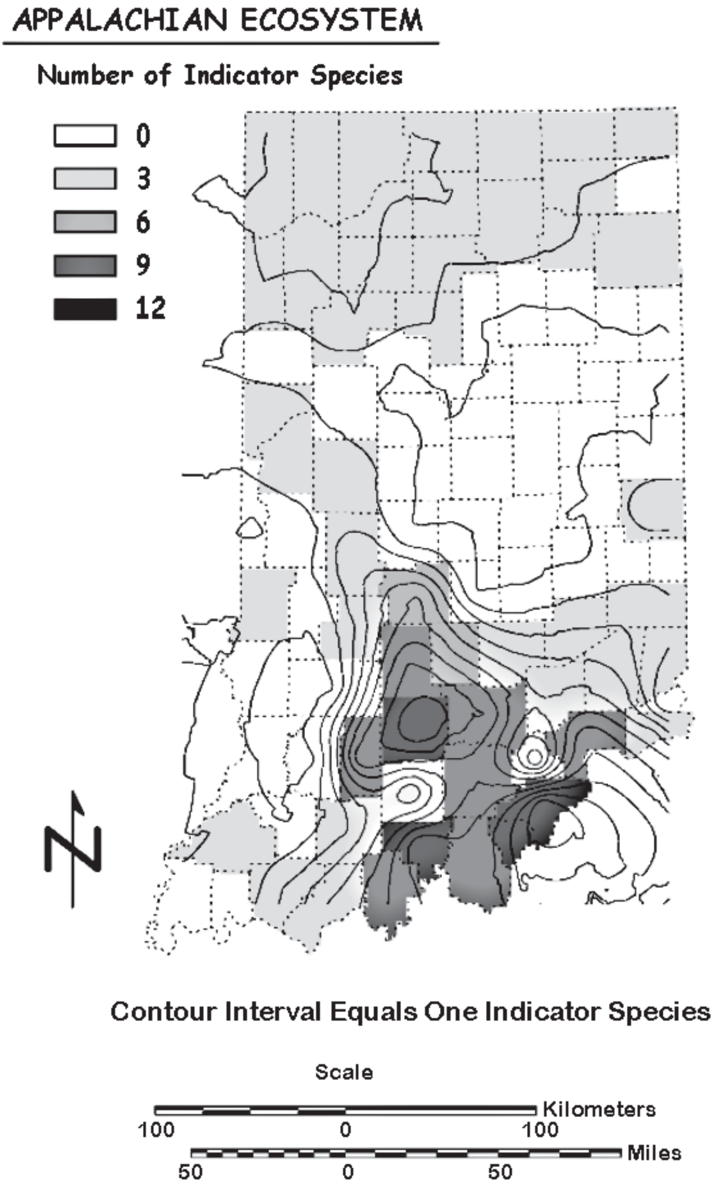

Figure 1: *Isolines draped over choropleth map showing relative indicator species abundance for Appalachian ecosystem.*

one third or more indicator species could be confidently included within a particular ecosystem and that areas with less than this proportion of indicator species represented transitional zones between adjacent ecosystems.

An indicator species diversity surface (ISDS) was then generated by developing a measure of indicator species diversity referred to as the indicator species diversity index (ISDI). This index is a function of the number of systems represented, total number of indicator species, and variability of the number of species occurring within each ecological system.

$$\text{ISDI} = \frac{\text{ES}^2 \text{ x TIS}}{\text{SDIS} + \text{TIS}} \text{ x V}$$

where:

ES = number of ecological systems in that county,
TIS = total number of indicator species in that county,
SDIS = standard deviation of indicator species from each ecological system occurring in that county.
V = a scaling factor, in this case 10.

This index operates such that a county having an equal number of indicator species within three different ecological systems will have a higher index value than a county with a majority of species occurring in one ecological system and only a few in the other two. For example, consider a county with 5 indicator species occurring in each of 3 different ecological systems; the ISDI for this county is 9. If the same county had 3 indicator species occurring in two systems and 9 in the other, the ISDI would be 7.3. Finally, if 13 indicator species occurred in one ecological system, and only one in each of the other two, the ISDI would be 6.2. If only one ecological systems is represented the ISDI will always be 1, regardless of the number of indicator species present. This eliminates any sensitivity to the number of indicator species recorded in each county or within each ecological system.

The ISDS was then constructed by interpolating a surface based on the ISDI calculated for each county using the Arc/Info IDW function. This surface portrays the spatial distribution and ecological diversity of these five ecosystems within the state based

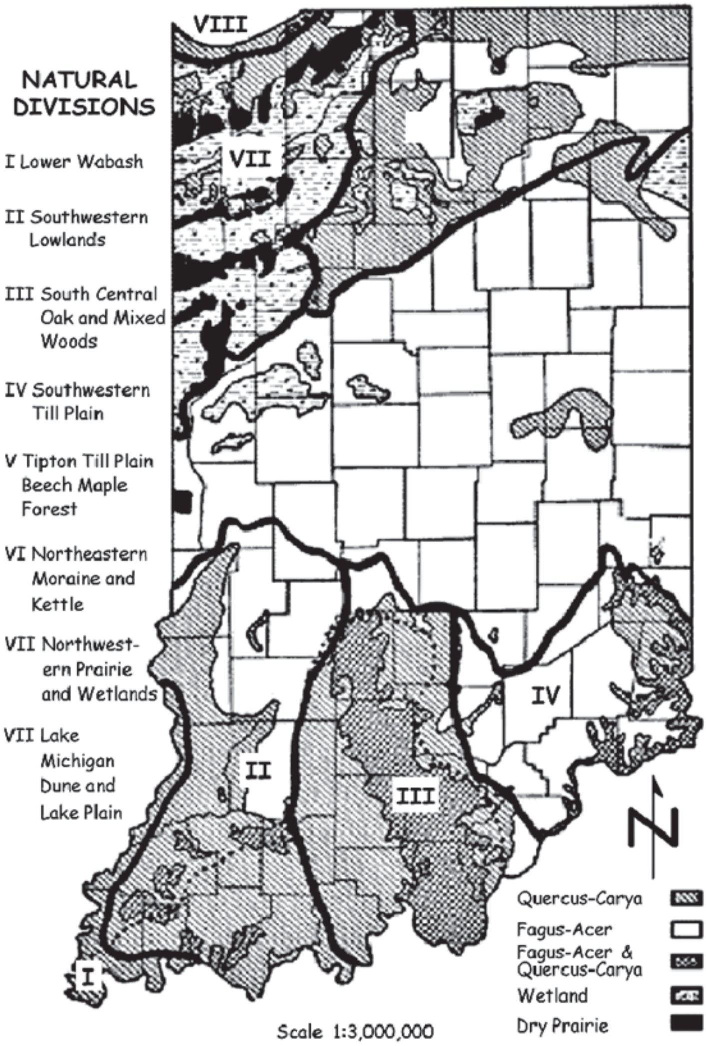

Figure 2: *Natural regions of Indiana (Lindsay et al. 1969).*

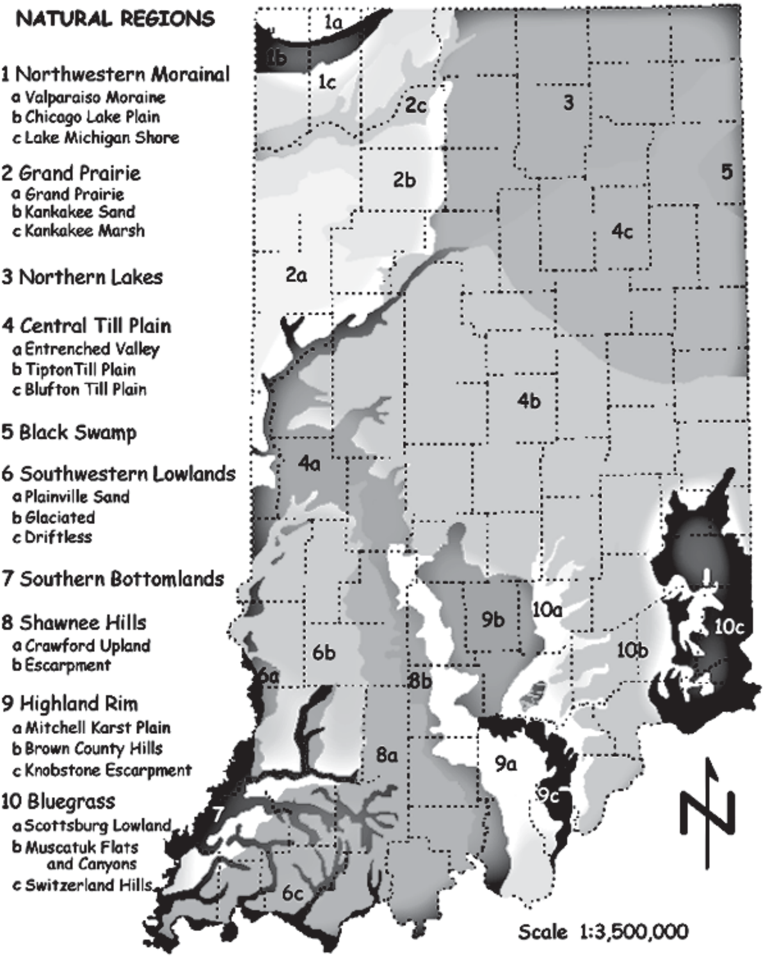

Figure 3: *Natural regions of Indiana (Homoya et al. 1985).*

on the number of indicator species occurring within each system. The ecosystem boundaries previously constructed were then draped over this ISDS. The intent is to cartographically depict the distribution of these ecosystems and also convey additional information concerning the diversity within and between each ecological system.

Results and Discussion of Indicator Species Analysis

The distribution and location of the regions discussed in the following text refer to the natural divisions of Lindsey et al. (1969) (figure 2) and natural regions of Homoya et al. (1985) (figure 3). Numbers and roman numerals in parentheses following division, region, and section names refer to the corresponding labels on figures 2 and 3. The performance of indicator species analysis was assessed by comparing the results with existing regionalization schemes developed through traditional methods of ecogeographic analysis. Consequently, some discussion of the ecological character of these regions is required, however, the reader is referred to Lindsey et al. (1969) and Homoya et al. (1985) for a thorough discussion of the ecological characteristics of the natural divisions and natural areas of Indiana.

Interpretation of Indicator Species Diversity Surface:

The resulting ecological regionalization scheme based on the distribution of indicator species is presented in figure 4. As indicated earlier, the distribution of each of the five ecological systems considered was determined by identifying the isoline representing one third of the total number of indicator species included in each ecosystem. These ecological boundaries have been draped over the resulting ISDS and the boundaries and core areas have been labeled accordingly.

The ISDS indicates that the highest indicator species diversity values occur in the northwestern portion of the state, primarily within the Northwestern Morainal (1) natural region, and in the south central Shawnee Hills (8) and Highland Rim (9) natural regions. These are areas with 25 to 60 indicator species representing 2 or 3 of the five ecological systems considered and with ISDS

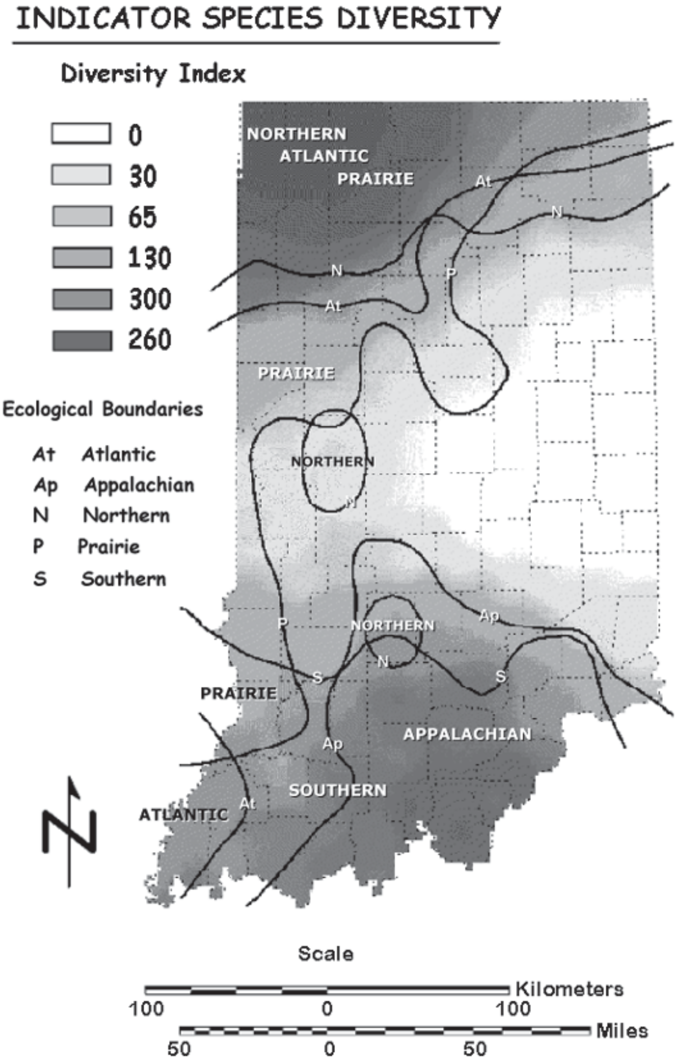

Figure 4: *Resulting ecological regionalization scheme based on the distribution of indicator species.*

values greater than 200. In the northwest, Atlantic, Northern, and Prairie indicator species occur in abundance, while in the south-central region there are significant numbers of Appalachian and Southern species which result in these high ISDS values. ISDS values of 65 to 200 occur in areas with 5 to 24 indicator species representing one or two of the five ecological systems. For example, higher ISDS values occur in the southwest corner of the state where the Southern and Atlantic ecosystems overlap within the Southwestern Lowlands (6) and Southern Bottomlands (7) natural regions.

ISDS values less than 65 occur in areas where only one ecological system is represented or in areas where less than one third of the indicator species in all systems occur. In the west central portion of the state, within and adjacent to the Prairie system, ISDS values range between 30 and 65. In this area a significant but less than critical number of indicator species from each ecological system occur.Figure 4 here.The lowest ISDS values occur in the east central portion of the state where few if any indicator species representative of these ecological systems are present. This simply suggests that none of the five ecological systems considered is represented in this area and does not suggest that there is an overall lack of biodiversity; only a lack of diversity with regard to the indicator species selected from the ecological systems considered.

This area roughly coincides with the Central Till Plain (4) and Black Swamp (5) natural regions and may be characterised by the occurrence of intraneous species having state-wide distributions. In Indiana, species such as white oak (*Quercus alba*), box elder (*Acer negundo*), butternut hickory (*Carya cordiformis*), shagbark hickory (*Carya ovata*), walnut (*Juglans nigra*), American elm (*Ulmus americana*), beech (*Fagus grandifolia*), black cherry (*Prunus serotina*), and sugar maple (*Acer saccharum*) occur state-wide and are of little value for the identification of ecological boundaries through indicator species analysis. Based on the results of these analyses, this area represents a broad transition zone between the southern third of the state, which is dominated by the Appalachian and Southern ecosystems, and the northern third of the state, which is dominated by Atlantic, Northern, and Prairie ecosystems. Thus, relative to the distribution of the five ecological systems considered here, this area is unclassified and represents a broad ecotone, although in reality it may be included within the Eastern Broadleaf Forest system which incorporates the majority of the state at a coarser scale of ecogeographic analysis.

It was suggested earlier that ecotones represent regions of maximum indicator species diversity, where species from adjacent ecological systems overlap. However, unlike the results obtained by Curtis (1959) in Wisconsin, where two floristic regions overlapped within a relatively narrow transition zone, in the case of Indiana several of the ecological systems considered overlap over much of their distribution within the state. For example, the Atlantic, Northern, and Prairie systems share a similar distribution over the northern third of the state, with the exception of the southwestern extension of the Prairie system. Consequently, although the maximum regional indicator species diversity does, in fact, occur within the region of overlap between these systems, it is not possible to identify this as an ecological transition zone at this scale of analysis. Since these five ecological systems represent broad continental scale biomes it may not be possible to identify the ecological transition zones between them within the state of Indiana alone. Similarly, the Appalachian and Southern systems share similar distributions in the southern third of the state and likewise a region of maximum indicator species diversity occurs within the area of overlap between these systems. This area may represent a portion of the ecotone between these systems within the state of Indiana but it is not possible to confirm this assumption at this scale of analysis.

The distribution of indicator species representative of these northern and southern ecosystems does not conveniently intersect somewhere in the middle of the state. Instead, we find a large region of low indicator species diversity characterised by intraneous species. It is possible that the addition of other indicator species or inclusion of an additional ecological system occurring within this area may alter the range of the five ecological systems considered and therefore the character of the ISDS. Alternatively, future research may attempt to include intraneous species in some manner such that we are able to account for regions that are otherwise undefined by the distribution of indicator species representative of the ecological systems considered.

Distribution of Ecological Systems:

In relation to the traditional state level regionalization schemes of Lindsey (1969) and Homoya et al. (1985) the distribution of these ecological systems is at a much coarser level of ecogeographic analysis and subsequently incorporates a number of the unique areas defined within these regionalization schemes. The Atlantic, Northern, and Prairie systems in the north occupy the majority of the Northwest Morainal (1), Grand Prairie (2), and Northern Lakes (3) natural regions of Homoya. These in turn correspond with the Northeastern Moraine and Kettle (VI), Northwestern Prairie and Wetland (VII), and Lake Michigan Dunes and Lake Plains (VIII) natural divisions of Lindsey. These regions fall within the Northern Moraine and Lake physiographic region characterised by intermittent lacustrine and outwash plain sediments over a vast area of till and end moraines.

The Appalachian and Southern systems in the south include Homoyas Soutwestern Lowlands (6), Southern Bottomlands (7), Shawnee Hills (8), Highland Rim (9), and Bluegrass (10) natural regions or Lindseys Lower Wabash (I), Southwestern Lowlands (II), South Central Oak and Mixed Woods (III), and Southeastern Till Plain Divisions (IV). The northern extent of the Southern and Appalachian systems corresponds well with the southern limits of Wisconsin and Illinoian glaciation respectively.

The southern extension of the Prairie system into the Southwestern Lowlands (6) natural area is identified by Homoya and is associated with edaphic factors affecting soil moisture capacity. The unclassified east central region of the state coincides with Homoyas Central Till Plain (4) and Black Swamp (5) natural regions and Lindseys Tipton Till Plain Beech-Maple (V) division.

Conclusions

It appears that the use of indicator species as described here may provide a useful alternative to traditional methods of ecogeographic analysis when the identity and distribution of species representative of the desired ecological systems is known in advance. It is likely that a more comprehensive regionalization scheme would be provided if every ecological system occurring within the study area at the given scale of ecogeographic analysis were considered. Further, it appears that a consideration of the scale of ecogeographic analysis as compared to the geographic extent of the study area is crucial. For example, the regionalization of continental scale biomes within a comparatively small study area, such as the state of Indiana, may provide results difficult to interpret due to the limited scope of the study area. Provided that the data are available it is recommended that the scale of ecogeographic analysis is at least one order higher than that of the study area considered. It should also be noted that this index only provides a measure of diversity with regard to the ecological systems considered and is not an indication of overall biodiversity.

Indicator species analysis, the ISDI and resulting ISDS provide a useful method of identifying and conveying information concerning the character of the resulting ecological regionalization scheme. In addition, they provide a means of identifying areas of exceptionally high or low indicator species diversity and, therefore, communicate information regarding the breadth and strength of interaction between adjacent ecological systems.

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