MONITORING BIODIVERSITY AND LANDSCAPE RICHNESS WITH DIGITAL EARTH IMAGERY

Richard H. Podolsky
The Island Institute, 60 Ocean Street, Rockland, Maine, USA 04841

ABSTRACT

Measuring and monitoring biodiversity and landscape richness for large portions of the earth is becoming increasingly important due to the acceleration of human impact on ecosystems. However, methods to do so have eluded ecologists. Here I present a method to estimate landscape diversity for large sections of the earth directly from digital imagery.

Landscape diversity was calculated by applying the Shannon-Weaver diversity index to data extracted from digital earth imagery. This index measures diversity by examining the "predictability" in a given data stream. The data supplied by the digital imagery to this diversity model are the area measurements for each spectral class in all or a portion of a SPOT multispectral image. Spectral classes appear to correlate well to specific habitats. Thus, the diversity of spectral classes for any point on earth is assumed to be a measure of habitat or landscape diversity. Area measurements for each habitat are extracted directly from the SPOT imagery via a pixel tallying routine mediated by GAIA software on a Macintosh II computer.

Landscape diversity and richness was calculated for the 423 islands in a SPOT Multi Spectral (MS) image. Generally, patterns of island diversity yielded results consistent with island biogeography theory. For example, landscape diversity of islands correlated positively to island size and convolutedness of island shorelines. Data also yielded a positive correlation between island landscape diversity and the richness of mammal species on 18 islands.

Monitoring and ultimately ensuring the biodiversity of the earth is of critical importance and it appears that digital earth image data sets and other remotely sensed data can play a vital role in this endeavor.

KEY WORDS: diversity, biodiversity, landscape, island, digital, imagery, global-monitoring.

INTRODUCTION

The richness and diversity of ecological systems have long fascinated ecologists. This fascination has focused on both the theoretical, for example, the relationship between a given system's diversity and its stability, and the practical implications of diversity. On the practical side, the general perception of ecologists and conservation biologists is that, all things being equal, diverse systems are more worthy of preservation relative to simpler systems (Wilson 1988). The reason for this is that diverse ecosystems appear to support richer assemblages of plants and animals than do simple ones. However, it must be pointed out that many "simple" systems support rare or endangered species whose protection is also critical.

The rate of human impact on the earth's surface has greatly accelerated in the second half of this century and is likely to accelerate further in the next 50 years. Thus we are faced with having to apply a triage approach to the question of which landscapes we should be preserving. Consequently, a methodology that quickly identifies regions of the earth with high diversity is of keen interest. The data and methodology reported here was motivated by this need for an efficient way of extracting estimates of relative diversity or richness at the landscape level.

Ecologists recognize three levels of diversity: alpha diversity (also called species diversity) which measures taxon diversity within a given ecosystem or habitat; beta diversity (also called landscape diversity) which measures diversity of habitats or landscapes within an ecosystem; and gamma diversity, which is the

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total diversity of a macro system such as an ecosystem, biome or continent (Suffling et al 1988). The diversity literature is dominated primarily by studies of alpha diversity (Peet 1974, Pielou 1975) in part because it has been easier to measure than beta or gamma diversity.

Regardless of the level of diversity being examined, two components of diversity are recognized. The first is richness, or the number of species or number of habitats present, and the second is evenness, or the distribution of individuals or habitats among species or landscapes (Peet 1974, Pielou 1975). Thus, estimates of alpha diversity for a given region requires two variables, the number of species present (also called species richness) and the relative abundance of each species. Beta diversity requires knowing the number of habitats in a given landscape (also called landscape richness) and the relative abundance of each habitat across a given landscape.

METHODOLOGY

Sources of Data, Preprocessing, and the Study Area

The data used to calculate diversity are the number of pixels for each spectral class in all or a portion of a SPOT multispectral image. I have personally visited more than half of the 423 islands in the study and conclude that the spectral classes of the preprocessed data correlate well to specific habitats or landscapes. I assume therefore, that the diversity of spectral classes for a given island is a measure of habitat or landscape diversity. Consequently, I use the terms spectral diversity, landscape diversity and habitat diversity interchangeably.

Landscape diversity and richness was measured directly from a full SPOT multispectral scene centered on Penobscot Bay, Maine (Figure 1.). The image was acquired October 27, 1988 and totaled 64.25 km^2 of which 423 islands comprised17.27 km^2. The remaining 46.98 km^2 was

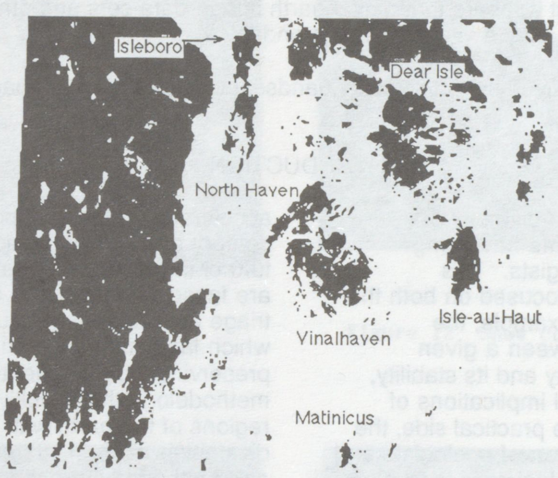

Fig. 1. SPOT Image scene of Penobscot Bay, Maine showing the larger islands. © [1988] CNES, provided by SPOT Image Corporation, Reston, VA.

comprised of water and mainland. Data on mammal species richness on 18 islands was provided by Crowell 1986.

Data were extracted from the image using GAIA software. GAIA allows the display, manipulation and analysis of a variety of digital earth images as well as the integration of vector maps on any 8 bit Macintosh II (Podolsky and Morehouse 1990 and Podolsky, et. al. 1990). File compatibility and data complexity dictate that the raw SPOT images be preprocessed. Preprocessing is a two step procedure. Step one converts SPOT data to Macintosh format and step two reduces the 16.7 million reflectance values (256

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values for each of SPOT's three spectral bands) to 64 habitat classes.

Preprocessing entails applying an unsupervised maximum likelihood clustering algorithm to the data thus reducing the SPOT imagery from 8 bit to 6 bit. Reflectance values cluster out within a three dimensional array defined by SPOT's three spectral bands. The algorithm reduces the data to 64 clusters and assigns each a unique value. During the final pass, every pixel is then given the value of the cluster within which it is most likely to fall (Lillesand and Kiefer 1987).

GAIA software served three major purposes in this study: accessing the satellite imagery; measuring distance to mainland and to yhe nearest larger island for each island; and exporting the imagery as a PICT II file. These exported PICT II images were analyzed with *Image* software package (Rasband 1990). I used *Image*'s particle analysis routines to measure the perimeter and area of each island as well as to tally the islands' spectral classes.

<u>Explanation of Terms: Area, Perimeter, and Convolutedness.</u>

All data extracted from the imagery was in pixel units and hence are accurate to the 20 meter resolution of the SPOT MS imagery. The SPOT data used in this study was acquired at high tide so all values for area and perimeter represent only the terrestrial portions of the islands.

In an effort to measure an island's convolutedness, I derived an index to indicate the degree to which a given island's perimeter varies from a circle's of equal area. The shape that yields the smallest perimeter for a given area is a circle and can be expressed:

$$P' = 2\pi\sqrt{\frac{A}{\pi}} \quad (1)$$

where P' is the smallest possible perimeter and A is the island's area. The index of convolutedness (C) is simply the ratio between an island's actual perimeter and its theoretical least perimeter:

$$C = \frac{P}{P'} \quad (2)$$

where P is the island's perimeter, P' is its least possible perimeter and C is the index of convolutedness. The more irregular an island, the higher its index of convolutedness.

<u>Landscape Richness and Diversity</u>

I used the total number of spectral classes present on an island as a measure of its landscape richness. As mentioned above, I assumed that an island with relatively high spectral class richness were also islands with high landscape or habitat richness.

I then inserted landscape richness values into the Shannon-Weaver index of diversity to derive an island's overall landscape diversity (Shannon and Weaver 1949). Typically this index is used to measure "species" diversity (Peet 1975). Diversity (H) is calculated by the equation:

$$H' = -\sum p_i \ln p_i \quad (3)$$

where p_i is the proportion of species i in a sample of s species. As the number of species in a system increases, especially if the relative proportions of those species are uniform, H will tend to be high. I calculated landscape diversity for each island of the 423 by substituting pixel tallies of each spectral class for species in the above model. In this way H will tend to increase when the number of spectral classes or habitats on an island is high and the proportions of those habitats are uniform.

I calculated maximum theoretical diversity (Hmax) for given habitat richness (s) to isolate those islands with uneven habitat distribution. Maximum diversity is defined as the Shannon-Weaver index resulting from perfectly even distribution of pixels in spectral classes. In such a situation, all p_i are equal and:

$$p_i = \frac{p}{s} \quad (4)$$

where p equals the total number of any given habitat class (because they are uniformly represented) and s is the total number of classes present. Substituting this equation into the Shannon-Weaver equation leaves:

$$H_{max} = -\ln\left(\frac{1}{s}\right) \quad (5)$$

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<u>Distance to Mainland and Nearest Larger Island.</u>

I calculated distance to mainland and distance to the nearest larger island for each of the 423 islands in the study using the measuring tool in GAIA. This tool returns the number of pixels between two user-defined points. I then converted those values into kilometers to produce a measure of an island's isolation.

<u>Diversity versus Biodiversity.</u>

According to the equilibrium theory of island biogeography (MacArthur and Wilson 1967) all things being equal larger islands and islands with long shorelines should equilibrate with greater numbers of plant and animal species than small islands with less shoreline. Also, islands with relatively high habitat diversity should support greater numbers of birds, mammals and other vertebrates. To test this I compared the richness of mammals among 18 islands (Crowell 1986) that varied with regards to size, habitat diversity, isolation and shoreline.

RESULTS AND DISCUSSION

Table one lists the variables that are readily extractable from satellite imagery using GAIA software. These islands, a subset of the 423 islands I surveyed, are the 18 islands for which mammal richness data is available.

Table 1. Example of data retrieved from SPOT MS imagery in conjunction with GAIA and Image software packages. (Mammal data from Crowell 1986)

NAME	P (km)	C	A(km^2)	s	H	Hmax	Dm(km)	Di(km)	MAM. (spp.)
Potato	0.49	1.19	0.01	14	2.34	2.64	14.08	0.24	1.3
Mark	0.72	1.14	0.03	25	2.77	3.22	16.99	1.04	2.1
Scraggy	1.22	1.79	0.04	21	2.42	3.04	17.99	1.46	2.0
Farrell	1.41	1.46	0.07	31	2.80	3.43	16.60	1.44	2.0
Rock	0.52	1.20	0.02	18	2.60	2.89	15.95	0.40	2.0
Matinicus	11.02	1.71	3.29	52	3.72	3.95	23.80	18.24	2.0
Camp	2.78	1.48	0.28	43	3.20	3.76	11.41	1.09	2.5
Eagle	6.36	1.59	1.27	51	3.68	3.93	10.11	2.89	3.0
Hardwood	0.93	1.10	0.06	31	3.06	3.43	16.91	0.51	3.0
Crotch	6.40	1.99	0.83	51	3.55	3.93	14.08	0.34	3.5
Merchants	6.93	1.93	1.03	50	3.29	3.91	16.29	1.55	4.5
Kimball	9.45	1.91	1.95	51	3.25	3.93	18.39	0.19	7.0
Isle-Au-Haut	45.19	2.44	27.23	51	3.35	3.93	16.83	10.11	10.0
Hog	6.95	1.76	1.24	42	2.78	3.74	0.25	0.67	10.0
Islesboro	75.70	3.91	29.83	52	3.50	3.95	2.50	12.09	10.0
Vinalhaven	138.43	5.24	55.46	53	3.69	3.97	10.60	9.50	11.0
Deer Isle	139.08	4.51	75.67	52	3.71	3.95	1.76	14.65	17.0
Second	0.54	1.15	0.02	17	2.26	2.83	16.56	0.61	1.5

P = perimeter; C = index of convolutedness; A= area; s = habitat richness; H = habitat diversity; Dm = distance to mainland; and Di = distance to nearest larger island.

Landscape diversity is positively correlated to island area (Figure 2.). This is consistent with the equilibrium theory of island biogeography (MacArthur and Wilson 1967) which reasons that larger islands have a greater likelihood of supporting a diverse array of habitats. Yet there are islands that are an exception to this pattern, that is, relatively large islands with low diversity. These "outliers" (set off by a box in Figure2.) turn out to be isolated outer islands exposed to environmental

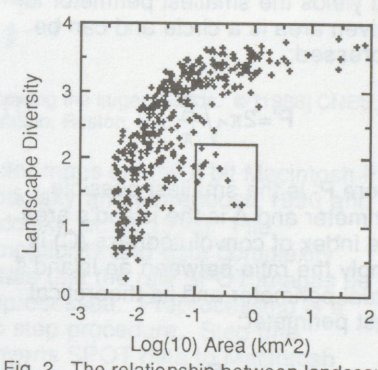

Fig. 2. The relationship between landscape diversity and island area for 423 islands in Penobscot Bay, Maine (the box indicates outliers discussed in text).

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extremes and consequently unable to support rich landscapes.

By definition, diversity is positively correlated with richness (Figure 3). Of interest however, is the fact that diversity more closely approaches

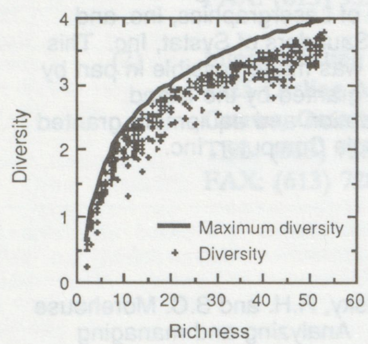

Fig. 3. The relationship of landscape diversity, landscape richness and maximum diversity for 423 islands in Penobscot Bay, Maine.

maximum levels when diversity and richness are low, and less likely to reach maximum levels when diversity and richness are high. This is because as the number of spectral classes on given island increases, the likelihood of equitable distribution of pixels among those classes declines.

The number of mammal species on islands is negatively correlated with distance of islands from the mainland (Figure 4.). This is because distant islands are more difficult for mammals to reach than island close to shore. Also, islands with high landscape diversity support richer assemblages of mammals than do islands with relatively low landscape diversity (Figure 5.)

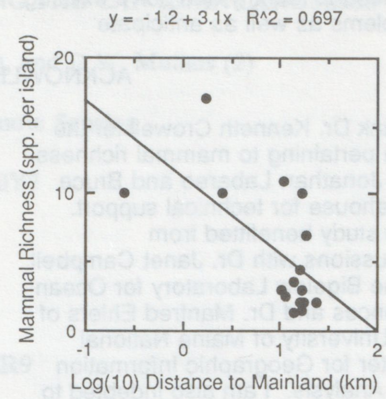

Fig. 4. Mammal species richness as a function of distance to the mainland for 18 islands in Penobscot Bay, Maine.

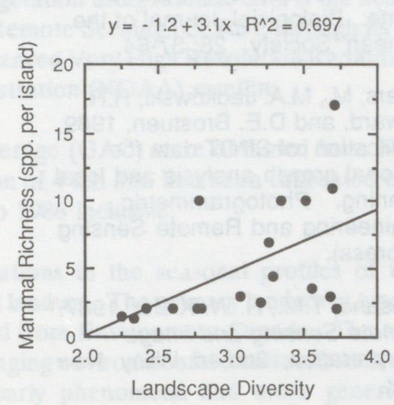

Fig. 5. Mammal species richness as a function of landscape diversity for 18 islands in Penobscot Bay, Maine.

CONCLUSIONS AND IMPLICATIONS

Although the study area for this work was a sample of islands within a single SPOT image scene, the methodology could easily be used to measure beta diversity for other landscapes. For example, nature reserves and habitat fragments could be measured and monitored through a similar approach. Similarly, gamma diversity could be measured by running the same analysis on entire SPOT or Landsat scenes or for that matter on suites of images covering thousands of square kilometers. It is also possible to "create" diversity maps that identify pockets of high landscape diversity (Podolsky in prep.).

Digital earth imagery represents a rich source of information of value to ecologists and conservation biologists. These data, in concert with microprocessors and analytical software tools, can allow ecologists to ask questions and derive answers at the landscape or geographic level. In the future, as the capabilities of microprocessors improves and software environments are created, ecologists will routinely reference these data. Thus it may be possible for analytical tools to keep pace with the increasing rate of human impact on the earth's surface. Most important however, is that the information derived from these data

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be used to identify and solve existing problems as well as anticipate problems before they occur.

ACKNOWLEDGEMENTS

I thank Dr. Kenneth Crowell for the data pertaining to mammal richness and Jonathan Labaree and Bruce Morehouse for technical support. This study benefitted from discussions with Dr. Janet Campbell of the Bigelow Laboratory for Ocean Sciences and Dr. Manfred Ehlers of the University of Maine National Center for Geographic Information and Analysis. I am also indebted to the following individuals and organizations for advice and support: Dr. Robert Metcalfe and David Newbold of 3COM Corporation, Bob Barker of SPOT Image Corporation, Bill Shelley and Roger Greene of Landmark Technologies, Candice Tuttle of Lasergraphics, Inc. and Lucy Saunders of Systat, Inc. This study was made possible in part by funds granted by the Island Foundation and equipment granted by Apple Computer, Inc.

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