A REMOTE SENSING AND GIS-BASED MODEL OF HABITAT AS A PREDICTOR OF BIODIVERSITY

DIANE DEBINSKI ♦ MUSEUM OF NATURAL HISTORY
UNIVERSITY OF KANSAS ♦ LAWRENCE

♦ INTRODUCTION

OBJECTIVES AND HYPOTHESES

The loss of biodiversity has become a global concern. Biologists are just beginning to grapple with issues of how to assess biodiversity and to create databases that can be valuable to a wide spectrum of users (e.g., Scott et al. 1990, Margules and Austin 1991). For conservation biologists to make decisions regarding the management of biological diversity, they need adequate floral and faunal inventories for the lands they manage. Species lists are only a first step in addressing large questions regarding relationships between species and their environments, and, in particular, species responses to environmental change. Understanding the environmental parameters that define species distributions is an even more important component of biodiversity assessment.

A variety of on-the-ground techniques have been developed for monitoring species distribution patterns, but they are labor-intensive and costly. After conducting a park-wide inventory of Glacier National Park for birds and butterflies (Debinski 1991), I began to investigate alternative methods to predict species diversity based upon landscape level habitat analysis (McLaughlin et al. 1992). My goal was to use limited field sampling to extrapolate species assemblage patterns within a region. During the summer of 1993, I initiated a research project using remote sensing and GIS analysis of landscape patterns to predict species assemblages of butterflies and birds in the Greater Yellowstone Ecosystem.

Spectral reflectance patterns are influenced by a combination of topography, moisture, elevation, and vegetation. As such, there is a strong correlation between habitat classifications and spectral reflectance patterns (Hillegers 1983). In fact, the Environmental Protection Agency's new biodiversity and habitat initiative is investigating the use of low-cost remote sensing data as a surrogate for ground based habitat assessment. Vertebrate biologists have been using knowledge of an animal's habitat to predict its presence or absence for decades (e.g., Baker 1956, Armstrong 1972) and remote sensing is now being used to identify species-specific habitat sites for animals (De Wulf et al. 1991, Saxon 1983). However, scientists are just beginning to use remote sensing data as a predictor of animal species assemblage patterns (Scott et al. in press). Here, I tested the hypothesis that plant and animal species assemblage patterns on the ground could be predicted by analyzing patterns of spectral reflectance as recorded by satellite remote sensing instruments.

There may be a real limit on the ability to distinguish different vegetation types based only on spectral reflectance. Proponents of Gap Analysis (a technique to compare locations of plant and animal habitats to those of existing preserves) are using LANDSAT Thematic Mapper (TM) imagery to determine boundaries of vegetation types and then incorporating other data (e.g. high altitude photography, aerial video-photography, ground-based vegetation maps and field surveys) to label the vegetation types to series level. A major criticism of this research is that Gap analysis does not involve enough ground-truth information. Even if the habitat appears suitable, we do not know how often a species actually occurs at the site. The focus of my research was to quantify the limits of remote sensing for predicting species assemblage patterns based on ground-truth data at a scale of 100 x 100 m sample sites.

The major objectives of the research were first, **to determine whether there is a relationship between spectral reflectance patterns as measured through remote sensing instruments and plant or animal species assemblage patterns.** I examined relationships between spectral reflectance patterns and vegetation type, and then between animal assemblages and spectral reflectance patterns. The second objective was **to test the ability to predict species assemblages based upon knowledge of this relationship.** If spectral reflectance patterns and microhabitat types prove to be good predictors of species assemblages, this technique could save both private conservation groups and government agencies vast sums of money in monitoring biodiversity. However, if these relationships do not hold, fewer ground surveys will be necessary. The goal is not to do away with ground-based fieldwork, but rather to optimize the ability to do extensive sampling using remote sensing and GIS to extend field measurements. The final objective was **to determine which remote sensing bands, band combinations, or band transformations are most useful for predicting species assemblages.** The first objective was pursued during 1993. Objectives two and three will be pursued in future years.

STUDY AREA

The study area for this research project was the northwest corner of the Greater Yellowstone Ecosystem, from Porcupine Creek to Bacon Rind (north/south) and from the crest of the Madison range to the crest of the Gallatin range (east/west). This area was chosen for three reasons. First, it is one of the largest intact ecosystems in the continental U.S. and includes a wide range of elevation and moisture gradients. This will allow me to investigate the effects of varying slope and aspect on the predictive capabilities of the model. Second, the patchiness of the post-fire successional habitats provides additional habitat types within which to test the hypothesis. Third, lists of birds and butterfly species are available for the ecosystem (Bowser 1988, Brussard 1989).

CRITERIA FOR CHOICE OF TAXA

Plants can be viewed both as a component of the species diversity, as well as a component of habitat diversity. The presence of a particular plant species in a specific site is highly indicative of the particular microhabitat of that site. Because plants play a major role in determining what reflectance patterns are measured by satellite, I believe that it is imperative that I test the relationship between plant species assemblages and remotely sensed habitat categorizations first. If plant species assemblage patterns cannot be predicted using remotely sensed data, correlations with animal taxa will be highly unlikely. Thus a plant survey is the critical link between remotely sensed data, habitat, and other species assemblage patterns. The 1993 fieldwork focused on tree species; future fieldwork will include shrubs and herbaceous plants.

Butterflies are a good choice for testing the hypothesis that remotely sensed data can be used to predict species assemblages. Some are moderately host-specific, while others are highly host-specific herbivorous insects and their diversity may be correlated with underlying plant diversity. Butterflies are well-known taxonomically and reliably identified in the field. Over one hundred different species reside in the Greater Yellowstone Ecosystem (Brussard 1989).

Birds are a suitable taxonomic group to test the hypothesis because they are ecologically diverse and use a wide variety of food and other resources. Therefore, they reflect the condition of many aspects of the ecosystem. They also represent several trophic groups or guilds, and by having a short generation time, they exhibit quick responses to environmental change (Steele et al. 1984). Finally, they are good indicators because they are conspicuous, ubiquitous, intensively studied, and often appear to be more sensitive to environmental changes than other vertebrates (Morrison 1986).

♦ METHODS

GIS AND REMOTE SENSING ANALYSIS

Sampling sites were selected based upon a combination of GIS analysis and field surveys. The remotely sensed data included three visible, one near infrared, and two middle infrared bands. Landsat 5 Thematic Mapper (TM) data from a 31 July, 1991 scene were registered to a Universal Transverse Mercator (UTM) coordinate system using ground control points selected from maps covering the study area, and resampled to 30 x 30 meters. Digital elevation model (DEM) data were obtained from the U.S. Geological Survey (USGS) with the assistance of the Gallatin National Forest, projected to UTM coordinates, and the maps of slope, aspect, and elevation created using ERDAS GIS software. TM pixel brightness values were converted to radiance values (watts/m^2/steradian/nanometer) to account for effects of changing instruments and calibration drift. Six bands were available to describe each 30 x 30 m pixel. TM data transformations were used to extract vegetation information (i.e., tasseled cap, PCA, and normalized difference vegetation index (NDVI)). To avoid sampling on cliffs or extremely steep slopes, areas of greater than 30 degrees slope were masked out on the Landsat data.

These remotely sensed data were then clustered into 50 spectrally distinct classes, and classified using a minimum distance classifier. Cluster classes were evaluated using U.S. Forest Service (USFS) stand survey maps, aerial photography, and personal knowledge of the study area. The 50 classes were then combined to form eleven spectrally distinct vegetation cover types. To facilitate location of study sites during fieldwork, the map was converted to vector format and plotted on translucent Mylar, allowing overlay onto a 1:24,000 scale USGS topographic maps of the study region.

Five forest habitat types and six meadow habitat types were identified in the preliminary analysis. Forest types included *Pseudotsuga menzesii*, *Pinus albicaulis*, and mixed conifer *Pinus contorta*, *Picea englemanii*, and *Pseudotsuga menzezii* of three different densities F1-F3. *Populus tremuloides* stands were so rare and small that they did not emerge as a distinct group. Meadows ranged from M1 (extremely hydric) to M6 (extremely xeric). Mapwork and field surveys were then used to identify five spatially distinct examples of each of the habitat types. Sample plots of 100 x 100 m were staked out at each of the sites.

SPECIES AND HABITAT CHARACTERIZATION

Trees were sampled by establishing a 100 m transect on a side of the plot and surveying every tree within 3 m on either side of the transect line for species and Diameter at Breast Height (DBH). Presence/absence data was collected for butterflies and birds during 1 June - 8 Aug. 1993, employing previously developed methods (Debinski and Brussard 1992). Birds were surveyed from 0530-1000 hrs. in thirty-five sites comprising three forest types (F1-F3) and five meadow types (M2 - M6). Aural and visual surveys were conducted using four observers (two groups of two) moving systematically through the plots for 45 minutes. Bird surveys were repeated three times at each site during the course of a summer.

Butterflies were surveyed from 1000-1630 hrs. in 23 meadows of type M1-M6. Butterflies were censused by three people netting and releasing for 20 minutes in three randomly selected 50 x 50 meter subplots within each larger 100 x 100 m plot. Sites of this scale were chosen to minimize habitat heterogeneity. Sampling was repeated two or three times during the course of the 1993 field season for each of the 23 sample plots.

♦ RESULTS

Field surveys in 1993 validated the vegetation density and moisture gradients expected from satellite data interpretation. There was a definite gradient of increasing forest density from F1 to F3 forests. In addition, I observed that F3 forests tended to be located on steep, north-facing slopes. Ground-truth data confirmed the moisture gradient for meadows predicted from the satellite data. M1 and M2 meadows were sedge marshes with some standing water. M3 meadows were characterized by willow thickets and were located near streams. M4 meadows were of medium moisture with cinquefoil and mixed herbaceous vegetation, while M5 meadows had a mixture of sagebrush and herbaceous vegetation. M6 meadows were characteristically south-facing, rocky, and covered with sagebrush.

Discriminant analysis was used to determine whether F1, F2, and F3 forests differed significantly with respect to tree species composition and DBH. The same species were found over all forest types, but the relative abundance of each species and DBH were significant in discriminating between forest types (F = 21.73 for species and F = 7.971 for DBH; df = 2,502, a = 0.05, table value F = 3.07). F1 forests were composed of a combination of *Pinus contorta*, *Picea englemanii*, and *Pseudotsuga menzezii* while F2 forests were primarily *Picea englemanii* and *Pseudotsuga menzezii* with less *Pinus contorta*. F3 forests were primarily composed of *Picea englemanii* with less *Pinus contorta* and *Pseudotsuga menzezii*.

A total of 74 bird species and 38 butterfly species were observed during the surveys (Tables 1 and 2). Multivariate analysis of these data was conducted by using a modified presence/absence matrix which weighted the number of species occurrences relative to the number of times a site was surveyed. This data set provided more information than a simple presence/absence matrix. The number of occurrences of each species per site was summed over all the samples, rather than merely indicating whether or not the species has ever been seen at that site. In order to adjust for inconsistencies in sampling effort, each species/site combination was scored as $p_{ij} = m_{ij}/n_j$, where m_{ij} is the number of occurrences for species i, and n_j is the total number of samples taken at site j.

Preliminary analysis of the 1993 data indicated that several species of birds have a habitat preference (Table 1). Discriminant analysis of species assemblage patterns by habitat showed five bird species significantly correlated with one specific remotely sensed habitat type: Hammond's flycatcher *Empidonax hammondii*, F2; Willow flycatcher *Empidonax traillii*, M3; Dark-eyed junco *Junco hyemalis*, F1; brown-headed cowbird *Molothrus ater*, F2; and MacGillivray's warbler *Oporornis tolmiei*, M3. All of these species/habitat relationships make sense given known habitat preferences.

Several butterfly species were found only in hydric or xeric habitat groups (Table 2). Six butterfly species showed a habitat preference for dry meadows (e.g. M5-M6), or mesic to xeric meadows (M3-M6). Five species were found solely in M3 meadows, and one species *Boloria frigga* was found only in hydric meadows (M1-M3). Four species were found in all meadow types. However, none of the butterfly species was significantly correlated with one specific meadow type. This lack of significant relationships between butterflies and remote sensing habitat types may be partially due to a limited data set. 1993 was an extremely wet and cold summer; some butterfly sampling sites were only surveyed twice due to poor weather which limited sampling of butterflies. Finally, one would not expect all species to be significantly correlated with one remotely sensed habitat type. Species that were found in only a few sites do not provide enough data for rigorous statistical relationships. Similarly, species found in a range of habitat types (e.g. M1-M3) will not demonstrate a statistical correlation with one specific habitat type using discriminant analysis.

Habitat diversity was highest for both birds and butterflies in M3 meadows. M3 meadows supported a strikingly higher diversity of birds (41 species) relative to all other meadow and forest habitat types. M3, M5, and M6 meadows all supported high species diversity of butterflies (24, 23, and 23 species respectively).

Additional multivariate analyses will be conducted in the remaining grant period to determine whether species form statistically distinct assemblages independent of my preconceived habitat taxonomies. Multivariate analyses will also be conducted using species groupings (e.g woodpeckers, flycatchers, etc.) for birds and butterflies and habitat groupings (eg. mesic meadows, hydric meadows, forests versus meadows, etc.), rather than analyzing each species and each habitat separately. Funding will be requested for FY94-95 to 1) assess relationships between meadow vegetation (both shrubs and herbaceous plants) and remotely sensed habitat types and 2) augment the butterfly census data of 1993. From field observations, it appears that there will be significant relationships between remotely sensed data and meadow vegetation. However, these relationships have yet to be quantified. Additional butterfly surveys are necessary due to the weather limitations during the summer of 1993.

After the relationships between spectral reflectance and species assemblage patterns are elucidated, the objective of the future field seasons

Table 1. Bird species distribution relative to six meadow habitats (M1-M6) and three forest habitats (F1-F3). Meadow types incorporate a moisture gradient (M1, extrenekt hydric to M6, extremely xeric) and forest types incorporate a density gradient (F1, low density to F3, high density).

	M1	M2	M3	M4	M5	M6	F1	F2	F3
Vermivora celata			X					X	
Dendroica petechia			X					X	
Dendroica coronata			X	X	X		X	X	X
Dendroica townsendi									X
Oporornis tolmiei			X					X	
Geothlypis trichas		X	X				X		
Wilsonia pusilla			X						
Euphagus cyanocephalus	X	X		X	X	X			
Molothrus ater			X					X	
Piranga ludoviciana			X				X	X	X
Passerina amoena			X						
Pheucticus melanocephalus									X
Carpodacus cassinii			X			X	X	X	
Pinicola enucleator							X		
Carduelis pinus			X				X	X	X
Loxia curvirostra			X						X
Chlorura chlorura		X	X		X	X			
Passerculus sadwichensis		X		X					
Melospiza melodia	X	X	X	X	X	X	X	X	
Pooecetes gramineus		X	X	X	X	X			
Junco hyemalis			X	X	X	X	X	X	X
Tachycineta bicolor			X					X	
Spizella passerina		X	X	X		X	X	X	X
Zonotrichia leucophrys		X	X	X	X	X	X	X	X
Corvus brachyrhynchos				X			X	X	X
Perisoreus canadensis							X	X	
Cyanocitta stelleri						X		X	
Pica pica						X			
Nucifraga columbiana			X	X			X	X	X
Parus atricapillus			X				X	X	X
Parus gambeli			X	X			X	X	X
Sitta canadensis			X				X	X	X
Certhia americana							X	X	
Troglodytes aedon			X						
Turdus migratorius		X	X	X	X	X	X	X	X
Catharus guttatus							X	X	X
Catharus ustulatus							X	X	X
Catharus fuscenscens							X		
Sialia currucoides		X	X		X	X			
Myadestes townsendi				X		X	X	X	
Regulus satrapa			X				X	X	X
Regulus calendula			X				X	X	X
Sturnus vulgaris			X						
Vireo gilvus	X	X	X			X	X	X	
Stellua calliope		X							
Colaptes auratus	X	X			X	X	X	X	
Sphyrapicus ruber							X		
Sphyrapicus varius							X		
Sphyrapicus thyroideus							X		
Picoides villosus			X						
Picoides pubescens			X						X
Tyrannus verticalis									X
Sayornis saya							X		
Empidonax traillii			X						
Empidonax hammondii			X						
Empidonax oberholseri			X						
Empidonax minimus		X	X						
Contopus sordidulus								X	
Contopus borealis		X	X					X	
Tachycineta thalassina						X			
Iridoprocne bicolor		X	X	X	X	X			
Riparia riparia		X							
Stelgidopteryx ruficollis		X		X		X			
Petrochelidon pyrrhonota			X	X		X			

Table 2. Butterfly habitat specificity based upon results of 1993 field season. X denotes species presence in meadows M1 - M6, where M1 represents the hydric extreme of the moisture gradient and M6 represents the xeric extreme of the moisture gradient in the Greater Yellowstone Ecosystem.

	M1	M2	M3	M4	M5	M6
Parnassius pheobus					X	X
Parnassius protodice	X	X	X	X	X	
Pieris napi	X	X	X	X	X	X
Colias interior					X	X
Colias philodice						X
Colias eurytheme				X		
Colias pelidne						X
Anthocharis sara			X	X	X	X
Euchloe ausonides	X	X	X	X	X	X
Lyceana cupreus				X	X	
Gaeides xanthoides			X		X	X
Lyceana heteronea		X			X	X
Lycaena helloides		X	X			X
Lycaena mariposa			X			
Plebejus saepiolus		X	X	X	X	X
Plebejus icariodes		X	X	X	X	X
Plebejus acmon			X	X	X	X
Plebejus glandon			X			
Euphilotes enoptes			X			
Vanessa cardui	X	X	X	X	X	X
Nymphalis milberti		X		X		
Polygonia faunus		X				
Chlosyne palla			X			
Phyciodes tharos		X				
Physiodes campestris		X	X	X	X	X
Boloria frigga	X	X	X			
Boloria selene			X			
Boloria epithore		X	X	X	X	X
Speyeria atlantis		X	X		X	X
Speyeria mormonia			X	X	X	X
Cenonympha hadenii		X	X	X	X	X
Cenonympha inornata		X	X	X	X	X
Cercyonis oetus			X		X	X
Oeneis uhlerii					X	X
Oeneis chryxux					X	
Erebia epipsodea	X	X	X	X	X	X

will be to test the predictive capabilities of the model. I will use a clustering program to select sites with spectral reflectance patterns similar to the sites surveyed in 1993 and 1994 and predict the species assemblages that I expect to find in these unsurveyed sites. Expected species assemblages will be compared to observed species assemblages using discriminant analysis. The final step is to determine whether spectral reflectance patterns can be used to predict distributions of selected animal taxa.

♦ SUMMARY

The goal of this research is to explore new uses of remotely sensed data as predictors of plant and animal species assemblages. Tree species and mean DBH were both significantly related to remotely sensed forest habitat types. Several species of birds and butterflies were associated with one or more remotely sensed habitat types. Using single species and single habitat analyses, five bird species were significantly associated with remotely sensed habitat types. Additional sampling in 1994 will augment the butterfly data set and identify relationships between meadow vegetation and remotely sensed habitat types.

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