A remote sensing and GIS-based model of habitats and biodiversity in the Greater Yellowstone Ecosystem

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Abstract. We used remotely sensed data and geographical information systems (GIS) to categorize habitats, then determined the relationship between remotely sensed habitat categorizations and species distribution patterns. Three forest types and six meadow types in the Greater Yellowstone Ecosystem, USA, were classified using Landsat TM data. All plant species with 5% cover or greater, 31% of the butterfly species, and 20% of the bird species exhibited significant differences in distribution among meadow types. Sites of highest species richness coincided for plants, birds, and butterflies and were found in mesic meadows.

1. Introduction

As the current spasm of species extinction has become apparent (Wilson 1988, Reid and Miller 1989), land managers and biologists have sought to identify habitats important to the preservation of species diversity (hereafter termed biodiversity). A critical component of biodiversity protection is understanding the environmental parameters that define species distributions. Many studies have produced testable hypotheses relating variations in terrestrial species associations to inferred or measured variations of physical environmental factors (e.g. Simpson 1964, Terborgh 1970, James 1971, Pyle 1982, Owen 1990, Debinski and Brussard 1992, Kindscher 1994, Kindscher and Wells 1995). However, scientists have just, in the last decade, begun to use satellite multispectral imagery to aid in understanding community assemblage patterns (Saxon 1983, De Wulf *et al.* 1988, Scott *et al.* 1993, Stoms and Estes 1993).

Landscape level habitat analysis using remotely sensed data and GIS has the potential to aid in explaining species diversity patterns at fine-scale resolutions (Urban *et al.* 1987, Turner 1989). Furthermore, such analyses can help optimize sampling strategies to assure that each habitat type is sampled or to allow testing of hypotheses regarding the spatial correspondence of species diversity patterns among taxonomic groups (e.g. Prendergast *et al.* 1993). Gap analysis (Scott *et al.* 1993) relies on the use of remotely sensed data and GIS to categorize habitats, and then predict species assemblages expected to be found in those habitats. The goal of

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gap analysis is to compare predicted locations of plant and animal habitats to those of existing preserves, thereby identifying geographical gaps in habitat and/or species protection. One problem with this approach to conservation planning is that gap analysis has not been extensively tested to determine the accuracy of its predictions (Flather *et al.* 1995).

We used remotely sensed data and GIS to create maps that would aid in stratifying the habitats to guide biodiversity sampling in the Greater Yellowstone Ecosystem, USA. The objectives of the research were: (1) to determine the relationship between habitat categorizations based on spectral reflectance patterns and plant or animal species distribution patterns, and (2) to test the spatial correspondence among taxonomic groups for sites of high species diversity. Our research was similar to the approach used in gap analysis, but it was conducted at a finer scale (1 ha minimum map unit). We used plants, birds, and butterflies as taxonomic test groups. Because the plant species with dominant cover play a major role in determining the spectral reflectance patterns recorded by multispectral scanners, we thought it imperative to test the relationship between the remotely sensed habitat types and plant communities present. Butterfly species were chosen because they are relatively host-specific insects, and their diversity may be correlated with underlying plant diversity. Birds were tested because they are ecologically diverse, represent several trophic guilds, and by having a short generation time, they exhibit quick responses to environmental change (Steele *et al.* 1984).

The study area for this research project was a 32 375 ha area (figure 1) in the north-west corner of the Greater Yellowstone Ecosystem. Nonforest cover types within the ecosystem range from hydric willow (*Salix* spp.) and sedge (*Carex* spp.) meadows to high-altitude tundra and rock meadows (Knight 1994). Coniferous forest types within the ecosystem include lodgepole pine (*Pinus contorta* var. *latifolia*), subalpine fir (*Abies lasiocarpa*). Engelmann spruce (*Picea engelmannii*), whitebark pine (*Pinus albicaulis*), and Douglas-fir (*Pseudotsuga menziesii*). The Greater Yellowstone Ecosystem was chosen because it is one of the largest intact ecosystems in the continental US, so we expected species/habitat relationships to be less affected by human disturbance.

2. Methods

2.1. *GIS and remote sensing analysis*

The methodology for this study was directed toward producing a map of spectrally distinct vegetation classes within the Gallatin River study area. Landsat Thematic Mapper (TM) data are being used for vegetation mapping in the majority of state land cover/land use mapping projects currently underway in the United States. The Thematic Mapper records reflected light in six spectral bands (blue, green, red, near-infrared, and two mid infrared), with a spatial resolution of 30 m. The thermal band was not used for this mapping project. TM data of the study area for 31 July 1991 were converted from brightness values to units of radiance (mW cm^{-2} sr^{-1} μm^{-1}) (Markham and Barker 1986). The satellite data were georeferenced to plus or minus 0.5 pixel (15 m) accuracy and resampled to a Universal Transverse Mercator (UTM) coordinate system to match it with topographic maps of the region.

An Iterative Self-Organizing Data Analysis (ISODATA) clustering algorithm was applied to the four-band image file to identify spectrally similar pixels. The ISODATA algorithm operates by initially seeding a specified number of cluster centroids in spectral feature space. The euclidean distance between each pixel and each cluster
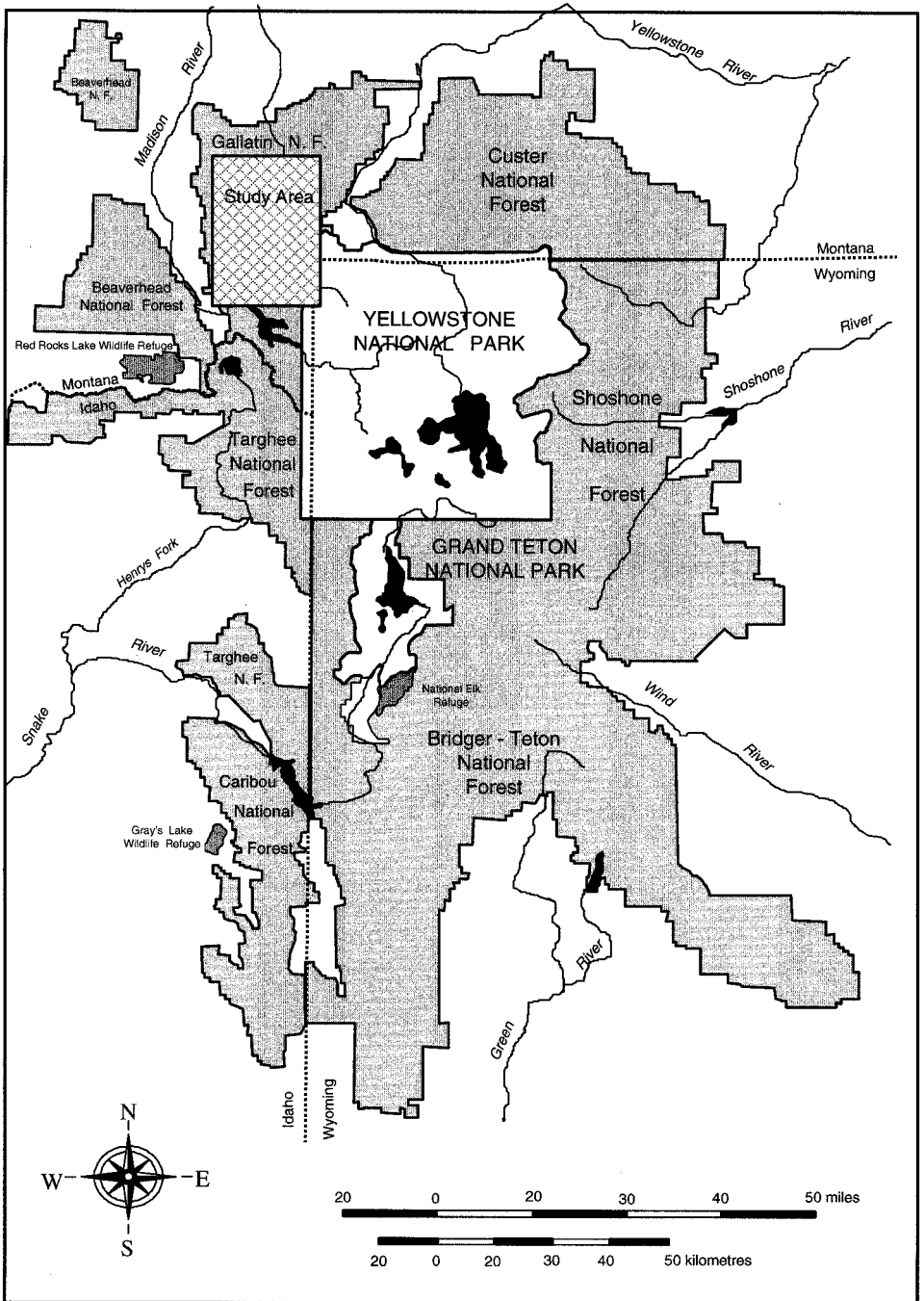
Figure 1.   The Greater Yellowstone Ecosystem (shown in grey) includes Yellowstone National Park and seven surrounding National Forests. Yellowstone National Park, in the centre, is shown in white. The study area (shown in hatched area) encompassed 32375 ha., including the north-west corner of Yellowstone National Park and south-east portion of the Gallatin National Forest.

centroid is calculated, and the pixel assigned to a cluster centroid (class). After each pixel is evaluated, a new series of cluster centroids are calculated based on the statistics of the pixels assigned to each centroid. The euclidean distance between each pixel and each cluster centroid is again calculated, and the pixel assigned, if necessary based on a shorter euclidean distance, to a different cluster centroid (class). The process of pixel evaluation-centroid recomputation continues iteratively until a threshold percentage (typically 95%) of pixels no longer change cluster centroid assignment.

Fifty initial clusters were specified for the ISODATA clustering, producing a map of fifty spectral classes. The number of clusters (spectral classes) specified for the ISODATA clustering algorithm takes into account the final number of information classes required for a project, the number of bands in the data set, and the complexity of the scene to be classified. We selected fifty initial spectral classes to enable us to discriminate not only between gross land cover types (forest versus meadow), but also among a gradient of meadow types (xeric to hydric). As such, with fifty classes, several spectral classes (groups of spectrally similar pixels) defined a single information class (e.g. xeric meadows) and were merged on the final map. Each spectral class was then identified using aerial photography and personal knowledge of the study region and assigned to an information class representing a vegetation type to create a final map of spectrally distinct vegetation classes. Six non-forested meadow classes, representing a distinct xeric-to-hydric gradient from sedge meadow (M1) to dry grassland with sagebrush (M6) were identified and mapped. Forest classes included Douglas-fir [DF], Whitebark pine [WB], and three densities of mixed conifer (lodgepole pine, Engelmann spruce, and Douglas fir), designated F1–F3 for sparse, medium, and dense stands. Non-vegetated areas (e.g. water bodies, roads, developed areas) were not included in the final vegetation map.

Since class polygons smaller than 1 ha would be difficult to locate with confidence in the field, the final vegetation map was converted to Arc/Info vector format and generalized to a minimum mapping unit of 1 ha (approximately 11 TM pixels), using the command ELIMINATE. For use in the field, final maps were plotted on translucent Mylar at a scale of 1: 24 000 for overlay onto topographic maps of the study area. We inventoried five spatially distinct examples of each of the F1–F3 and M1–M6 habitat types (nine habitat types, total sites = 45). Sample sites were located in the field with the aid of aerial photography, topographic maps, and compass readings from identifiable landmarks. Particular care was taken to ensure that sites were located in the center of a class polygon. Sites were limited to a 5 km distance from a road, so that accessibility was not too difficult for repeated sampling. Private property was not sampled. Sites were a minimum of 100 m by 100 m in size, and we avoided sampling extremely large sites (more than 2 km on a side). The WB and DF habitats were not sampled due to limitations in accessibility of the sites. Given all of these restrictions, there were very few subjective choices left in selecting sites.

2.2. *Species and habitat characterization in sample sites*

We chose sampling scales for the birds and butterflies based upon a combination of the average meadow patch size and the size of territories song birds and butterflies occupy. Plants were sampled at two different scales: one very fine-grained, and one much more coarse grained (almost the size of some of the smaller meadows). Grasses, forbs, and shrubs were surveyed in each of the 30 meadow types during 1994 and 1995. Meadow vegetation was surveyed at a fine scale during 1994 (25 1 m² plots

established at 4 m intervals along a 100 m transect) and at a coarse scale in 1995 (20 m by 20 m plots). We collected plant data at these two scales to facilitate the data collection process and to ensure that we could have species level accuracy for plant cover estimates. Each plot was surveyed for total coverage on a per species basis for all grasses, forbs, and shrubs. Plant taxonomy followed Dorn (1984). Species cover was determined by visually estimating the sum of the greatest spread of foliage for each species in each plot (Daubenmire 1959). In cases where species identification was problematic due to the phenological sampling time or taxonomic difficulties, species were lumped by genus to calculate a total cover for the genus rather than the species.

Presence/absence data were collected for butterflies and birds during 1993 and 1995, employing previously developed methods. Debinski and Brussard (1992) developed methods for bird and butterfly sampling in Glacier National Park, Montana, USA, which specifically focused on determining the minimum number of plots of each habitat and the minimum amount of time necessary to obtain accurate species list for montane meadows and forests in the Northern Rocky Mountains. Birds were surveyed from 0530–1000 hrs, in 35 sites (a subset of the 45 total sites) comprising three forest types (F1–F3) and six meadow types (M1–M6). Auditory and visual surveys were conducted using four observers (two groups of two) moving systematically through 100 m by 100 m plots for 45 minutes. Bird surveys were repeated three times at each site during the summer of 1993. Butterflies were surveyed from 1000–1630 hrs. in meadows only (five meadows of each type; total = 30 sites). Taxonomy followed Scott (1986). Surveys were conducted for 20 min periods by netting and releasing in three randomly selected 50×50 m subplots within each larger 100 m by 100 m plot. For most sites, surveys were repeated three times during the course of the 1993 and 1995 field seasons.

A Kruskal-Wallis test was used to compare plant species across areas sampled because the variances were found to be unequal using the Levene test in SPSS software (SPSS 1997) even after transforming the data (Sokal and Rolf 1981). Stepwise discriminant analysis (Harris 1985) of the bird and butterfly data was conducted by using a modified presence/absence matrix that weighted the number of species occurrences relative to the number of times a site was surveyed. 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.

3. Results

Analysis of the grass, forb, and shrub cover data revealed large differences in species distribution patterns among remotely sensed meadow types. We identified 142 species of plants in 1994 and 175 species during 1995 on the 30 meadow sites. We conducted Kruskal-Wallis tests on the dominant species (defined here as those species with a mean cover value $\geqslant 5\%$ in at least one meadow type). All 23 of the dominant plant species were statistically significant in determining differences among remotely sensed meadow habitat types in 1994, and 17 of the 26 species were significant in 1995 (tables 1 and 2). Half of the 24 species dominant in 1994 were also dominant in 1995.

Vegetation characterizing M1 and M2 meadows included *Carex* spp. and *Juncus* spp. with a high cover of *Salix wolfii*, *Scirpus spp.*, *Aster integrifolius* and *Fragaria virginiana* and some standing water. M2 meadows also had a high cover of *Poa* spp. M3 meadows were characterized by high cover of *Salix bebbiana*, *Carex* spp,

Table 1.   Mean grass, shrub, and forb percentage coverage in each of six remotely sensed meadow types (M1–M6) in 1994. Species noted below are those that had a mean cover value of at least five percent in at least one meadow type. A Kruskal-Wallis test was used to determine significant differences among the six meadow types (*** = $p < 0.001$).

Species	M1	M2	M3	M4	M5	M6	Significance
Achillea millefolium	2.32	5.42	2.44	4.81	2.73	2.35	***
Antennaria microphylla	0.06	0.06	1.18	0.38	4.98	2.01	***
Agropyron smithii	0.00	0.03	0.76	8.42	17.46	10.30	***
Artemesia cana	1.81	2.51	0.00	5.07	1.62	0.31	***
Artemesia tridentata	0.01	0.00	2.34	7.75	8.59	21.69	***
Aster integrifolius	20.66	9.58	2.38	0.65	0.23	0.06	***
Bareground	1.16	3.99	2.06	6.46	4.98	15.02	***
Bromus spp.	5.58	3.55	3.62	6.00	4.55	0.87	***
Carex spp.	43.86	19.66	19.06	5.50	2.69	1.15	***
Festuca spp.	1.52	3.51	9.60	20.18	35.51	31.59	***
Fragaria virginiana	12.34	8.29	10.52	8.06	4.93	0.01	***
Geranium spp.	0.39	0.93	2.86	5.65	0.83	0.00	***
Geum trifolium	0.18	1.72	3.19	7.97	6.64	0.00	***
Juncus spp.	26.74	8.41	2.42	0.02	4.60	0.00	***
Lupinus argenteus	0.00	0.00	0.86	2.06	2.01	5.37	***
Phleum pratense	5.07	8.40	2.75	5.66	5.34	0.17	***
Pentaphylloides floribunda	6.34	5.11	16.97	4.58	0.84	0.00	***
Poa spp.	4.86	33.22	14.98	13.02	10.22	7.68	***
Potentilla spp.	3.05	3.00	4.09	12.16	8.67	0.13	***
Salix bebbiana	2.46	0.00	6.28	0.00	0.00	0.00	***
Salix wolfii	10.73	15.14	0.00	0.00	0.00	0.00	***
Senecio pseudaureus	8.04	1.80	0.03	0.07	1.98	0.03	***
Solidago missouriensis	0.12	1.43	0.30	0.00	0.29	5.11	***

Pentaphylloides floribunda, *Poa* spp., and *Fragaria virginiana* and tended to be located near streams. M4 meadows were of medium moisture with *Stipa richardsonii*, *Bromus* spp. (specifically *Bromus anomalus*), and mixed herbaceous vegetation (e.g. *Potentilla spp.*, *Lupinus argenteus*, *Geum triflorum*, and *Geranium* spp.), while M5 meadows had a mixture of *Artemesia tridentata*, *Agropyron smithii*, *Festuca* spp., and mixed herbaceous vegetation (e.g. *Antennaria microphylla*, *Geum triflorum*, and *Potentilla* spp.). M6 meadows were characteristically xeric, rocky, and dominated by *Artemesia tridentata*, *Agropyron smithii*, *Festuca* spp., and bare ground.

A total of 74 bird species and 42 butterfly species were observed during the surveys. Stepwise discriminant analysis showed fifteen species of birds (20%) exhibited at least one statistically significant habitat preference (table 3). Seven bird species had significantly different frequencies in forest versus meadow habitats: Mountain Chickadee, Brown Creeper, American Crow, Orange-Crowned Warbler, Hermit Thrush, American Robin, and Song Sparrow (scientific names in table 3). All of these species except the Song Sparrow showed a preference for forest. The Orange-Crowned Warbler did not have as striking a difference in frequency of occurrence, but this difference was statistically significant and it does make sense given the known habitat preferences of the species. When habitats were clumped into broad categories, (M1–M2, M3–M4, M5–M6, and F1–F3) preferences were as follows: The Mountain Chickadee preferred forest over meadow; it is usually found in coniferous forest. The Song Sparrow and Rufous-sided Towhee preferred wet willow meadows

Table 2.   Mean grass, shrub, and forb percentage coverage in each of six remotely sensed meadow types in 1995. Species noted below are those that had a mean cover value of at least five percent in at least one meadow type. A Kruskal-Wallis ANOVA was used to test for significant differences in mean percent cover among the six meadow types ($* = p < 0.05$, $** = p < 0.01$, $*** = p < 0.001$).

Species	M1	M2	M3	M4	M5	M6	Significance
Agropyron smithii	0.00	1.52	0.02	3.25	27.33	13.63	**
Aster campestris	0.00	5.17	0.84	0.88	0.67	3.83	ns
Bareground	0.00	0.00	0.00	7.75	6.00	10.25	**
Bromus anomalus	0.00	0.00	0.00	19.00	0.00	0.00	*
Bromus mollis	0.00	3.20	10.20	0.00	1.17	0.00	*
Carex 2 spp.	6.30	0.03	0.00	0.00	0.02	0.00	ns
Carex 3 spp.	31.80	3.83	9.60	0.05	0.00	0.00	**
Carex 5 spp.	12.40	16.50	8.40	0.00	0.00	0.00	ns
Carex 4 spp.	0.00	0.00	0.02	0.00	6.52	0.03	**
Carex 1 spp.	50.70	20.37	18.56	0.05	6.52	0.03	ns
Festuca ovina	0.00	3.00	2.20	1.53	17.83	14.25	**
Fragaria virginiana	4.04	8.62	20.82	0.03	0.13	0.13	*
Geranium viscossimum	0.00	0.37	6.72	10.53	1.03	0.00	*
Geum triflorum	0.00	9.68	8.44	2.25	2.55	0.13	ns
Lupinus argenteus	0.00	0.00	0.26	1.28	6.08	1.58	**
Pentaphylloides floribunda	0.16	1.67	13.20	0.00	0.02	0.05	*
Phleum pratense	0.04	1.50	0.08	5.63	9.33	0.03	ns
Salix bebbiana	0.00	0.00	9.60	0.00	0.00	0.00	ns
Salix wolfii	21.26	13.83	0.20	0.00	0.00	0.00	*
Scirpus spp.	56.22	10.02	6.80	0.00	0.00	0.00	***
Senecio hydrophilus	9.10	0.67	0.00	0.00	0.00	0.00	**
Senecio integerrimus	7.10	1.00	0.02	0.03	0.00	0.03	**
Smilacina stellata	0.02	0.12	5.82	0.00	0.08	0.00	ns
Stipa nelsonii	0.00	4.50	0.64	0.13	8.52	0.00	ns
Stipa richardsonii	0.00	0.00	0.24	0.00	10.00	1.75	*
Trifolium longipes	3.08	6.52	0.06	0.03	0.02	0.00	**

Note: Carex spp. in this list were divided into morphospecies groups due to collection during the time when all flowering parts were not available.

(M1–M2). The Dark-Eyed Junco preferred forest over meadow. The Violet-Green Swallow and the Hairy Woodpecker preferred dryer meadows. Significant differences among forest preference were as follows: The American Robin and Red-Breasted Nuthatch preferred the denser forest (F3), while the Ruby-Crowned kinglet preferred more open forests (F1) and the Song Sparrow preferred the medium density forests (F2).

Several butterfly species (31%) showed significant relationships with one or more specific remotely sensed habitat types (table 4). A total of ten species were found on only one meadow type, yet another ten species were found in all meadow types. Four butterfly species showed a habitat preference for wet meadows, four species preferred intermediate moisture meadows, and two species preferred dry meadows. *Euphydryas gillettii*, a known habitat specialist, was found only in M1 meadows and *Colias eurytheme* was found only on M4 meadows. However, most of the species could not be considered specialists in one meadow type, but rather showed preferences for meadows in the hydric range (*Boloria epithore*, *B. selene*, and *B. frigga*), the xeric range (*Plebejus icariodes* and *Coenonympha inornata*) or the mesic range (*Anthocharis sara*, *Speyeria mormonia*, and *Euchloe ausonides*). *Vanessa cardui* and

Table 3.   Frequency of occurrence of bird species significantly related to remotely sensed habitat types based upon result of stepwise discriminant analysis. Species are listed in order of inclusion in stepwise discriminant analysis.

Species	Meadow	Forest
Meadow versus Forest Categorization (alpha= 0.05)		
Mountain Chickadee (*Parus atricapillus*)	0.030	0.482
Brown Creeper (*Certhis familiaris*)	0.000	0.130
American Crow (*Corvus brachyrhynchos*)	0.015	0.148
Orange-crowned Warbler (*Vermivora celata*)	0.015	0.019
Hermit Thrush (*Hylocichla guttata*)	0.000	0.130
American Robin (*Turdus migratorius*)	0.394	0.648
Song Sparrow (*Melospiza melodia*)	0.561	0.037

Species	M1–M2	M3–M4	M5–M6	F1–F3
Clumped Habitat Categorization (alpha= 0.05)				
Mountain Chickadee (*Parus atricapillus*)	0.000	0.067	0.000	0.482
Song Sparrow (*Melospiza melodia*)	0.800	0.600	0.333	0.037
Rufous-sided Towhee (*Pipilo erythrophthalmus*)	0.067	0.000	0.000	0.000
Dark-eyed Junco (*Junco hyemalis*)	0.133	0.483	0.238	0.926
Violet-green Swallow (*Tachycineta thalassina*)	0.000	0.000	0.095	0.000
Hairy Woodpecker (*Dendrocopos villosus*)	0.000	0.033	0.000	0.000

Species	F1	F2	F3
Differences Among Forest Categorizations (alpha= 0.1)			
American Robin (*Turdus migratorius*)	0.548	0.528	0.933
Red-breasted Nuthatch (*Sitta canadensis*)	0.500	0.500	0.800
Ruby-crowned Kinglet (*Regulus calendula*)	0.714	0.667	0.600
Song Sparrow (*Melospiza melodia*)	0.048	0.055	0.000

Table 4.   Occurrence of butterfly species significantly related to remotely sensed habitat types based upon results of stepwise discriminant analysis. Species are listed in order of inclusion in stepwise discriminant analysis (*alpha= 0.05*).

Species	M1	M2	M3	M4	M5	M6
Euphydryas gillettii	7	0	0	0	0	0
Boloria epithore	12	21	31	8	12	4
Plebejus icariodes	6	13	37	23	32	33
Coenonympha inornata	0	9	10	11	20	25
Boloria frigga	7	3	1	0	0	0
Cercyonix oetus	0	0	4	0	4	11
Anthocharis sara	1	1	11	4	9	1
Speyeria mormonia	0	0	15	4	8	8
Vanessa cardui	22	16	22	21	24	10
Boloria selene	2	2	5	0	0	0
Colias eurytheme	0	0	0	3	0	0
Euchloe ausonides	12	19	35	22	16	16
Plebejus saepiolus	21	14	18	11	21	13

Plebejus saepiolus showed even less of an affinity for a specific meadow type, despite showing significance in the discriminant analysis.

4. Discussion

Because the remote sensing image measures energy reflected by plants and the ground surface, and because the plant data were more quantitative than the animal data, we expected the habitat categorizations based on these reflectance patterns to show strong relationships with plant species distribution patterns. We expected the relationships to be less strong between animal species and remotely sensed habitats because the animal data were measured as presence or absence and animals may or may not be present at a site when data are being collected. Our results supported our expectations. All of the dominant plant species showed differences among meadow types using fine-grained sampling and 65% showed significant differences using the coarse-grained approach. However, the dominant plants comprised less than 20% of the total plant species list. We had not expected so many plant species to have low percentage coverage. Finding relationships between low-cover species and the remotely sensed habitats would probably be more difficult. By definition, we did not have enough data on low-cover plant species to rigorously test this hypothesis. As for the differences in statistical relationships between the two plant data sets, we would expect that these differences were a result of the sampling scale and not simply a year effect because a large portion of the plant species were perennials. Sampling at both scales during the same year would be necessary to sort out the relative importance of years versus sampling scale.

Butterflies and birds showed clear preferences for certain habitats. Butterflies had a higher percentage of total species statistically correlated with specific habitat types; birds were comparable to plants in percentage of significantly correlated species. Comparing birds and butterflies, the butterflies were most highly correlated with remotely sensed habitat types on a percentage basis. The number of significant relationships found in the butterfly data was surprisingly high, but it may be explained by the habitat specificity and host-plant specificity of many of these species. Butterflies key into the chemical composition of a plant, while birds key into the structure of the plants, but diversity of vegetation is an asset for both birds and butterflies.

In summary, 20–30% of animal taxa and 65–100% of the dominant plant species were significantly correlated with one or more remotely sensed habitats. Some of the species that showed significant relationships were quite common. However, rare animal species showed significant relationships with remotely sensed habitat types if they were highly specialized in their habitat utilization (e.g., *E. gillettii*). These results are partially a function of sampling intensity. With a higher level of sampling intensity, or if abundance data were used rather than presence-absence data, we might expect an even larger number of species to show significant relationships.

Thus, in order to build predictive models of species habitat relationships using remotely sensed data and GIS methods, a species must be either common enough and/or habitat-specific enough to exhibit a significant relationship with one or more remotely sensed habitat types. The implication for biodiversity management is that rare species may need to be surveyed using more field intensive methods in order to build more highly predictive models. Our approach could be quite valuable in determining potential sites for species with specialized habitat requirements or in large parks and reserves where the distribution of flora and fauna are not well known.

Acknowledgments

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