MODELING SPATIAL AND TEMPORAL DYNAMICS OF MONTANE MEADOWS AND BIODIVERSITY IN THE GREATER YELLOWSTONE ECOSYSTEM

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✦ OBJECTIVE OF RESEARCH

Our project is an examination of ecological dynamics in the Greater Yellowstone Ecosystem (GYE), concentrating specifically upon the spatial and temporal dynamics of montane meadow communities. We are examining both the abiotic aspects of these communities as well as the biodiversity of plant, bird and butterfly communities. Our long-term goal is to develop predictive species assemblage models based upon landscape level habitat analysis. This involves using intensive, local field sampling to test for relationships between species distribution patterns and remotely sensed data. This research involves several steps: 1) quantifying the spatial and temporal variability in montane meadow communities; 2) developing a spectrally-based spatially-explicit model for predicting plant and animal species diversity patterns in montane meadows; and 3) testing the spectrally-based spatially-explicit model for predicting plant and animal species diversity patterns in montane meadows.

✦ PROGRESS SUMMARY

We are using a time series of satellite multispectral imagery for monitoring the extent, condition, and spatial pattern of montane meadows on a seasonal and interannual time scale. Field sampling is being used to collect data on the distribution of plant, bird, and butterfly species. Spectrally-based, spatially-explicit models are being developed for six meadow types using a GIS to stratify the study area by topography and geology. We have sampled for three years in two regions of the ecosystem: the northern part of the ecosystem, hereafter termed the Gallatin study area, included the Gallatin National Forest and northwestern portion of Yellowstone National Park; the southern part of the ecosystem, hereafter termed Teton study area, included Grand Teton National Park. Twenty-five sample sites were located in the Tetons and thirty sample sites were located in the Gallatins during 1997 and 1998. Birds, butterflies, and plants were surveyed at each of the sites. Details of the sampling methodology and data analysis are noted below.

During the summer of 1999, we mounted a field campaign that will allow us to test the predictability of our models within each region. We visited new sites of each meadow type in each sampling area for collection of bird, butterfly, and plant data. This field season focused on extensive rather than intensive data collection (i.e., we visited many new sites, but collected data less frequently at each site). In 1999, 40 new sites were added in the Tetons (8 of each meadow type) and 34 new sites were added in the Gallatins (5-6 in each meadow type).

Two Master's theses have been produced as a direct result of this research (Saveraid and Borgognone).

✦ ACCOMPLISHMENTS AND RESEARCH RESULTS

Meadow Map Production

Computer classification of multitemporal SPOT multispectral satellite imagery was used to produce maps of spectrally distinct meadow classes within the Gallatin and Teton study areas. The SPOT satellite remote sensing system records reflected light in three spectral bands (green, red, and near-infrared), with a spatial resolution of 20 m. A summer and a fall date of SPOT multispectral imagery were selected for each study area. A multitemporal approach, using two seasons of data, has been proven in other research to be superior for land use/land cover mapping. Data for May 25 and September 6, 1994 were used for the Gallatin National Forest; data from June 17 and September 3, 1996 were used for the Teton study area. Selection of dates was a function of orbital revisit dates, cloud cover, and availability.

Data were converted from brightness values to units of radiance (mW/cm2/sr/um) and then reflectance. Data were further normalized for differential illumination effects by performing a topographic normalization procedure, using the DEM data re-sampled to 20 m. All satellite imagery were georeferenced to a Universal Transverse Mercator (UTM) coordinate system with a pixel size of 20 m. The three-band multispectral data for the summer and fall dates for each area (Teton and Gallatin) were then combined into a six-band data file for each study area.

An Iterative Self-Organizing Data Analysis (ISODATA) clustering algorithm was applied to each six-band image file to identify spectrally similar pixels. Thirty to fifty initial clusters were specified for the ISODATA clustering, producing a map of spectral classes. Each spectral class was then identified and assigned to an information class representing a vegetation type. Based on spectral similarity, and visual interpretation of the classes with the assistance of aerial photography and knowledge of the study area, the spectral classes were combined to create a five-class map of coniferous forest, water, developed lands, deciduous forest, and non-forested (meadow) vegetation. This five-class map was then recoded to a binary map of meadow/non-meadow, and used to mask the six-band image file, producing a new image file containing data only for meadow areas. ISODATA clustering was again applied to the masked data to identify spectral differences in the meadow class only, producing a final map of distinct meadow 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. FRAGSTATS computer program is being used to analyze landscape differences in meadow size, distance to next meadow of the same type, and type of adjacent habitat between sampling areas. These landscape-level parameters may have significant effects on species distribution at a particular point in the ecosystem.

Selection of Sampling Sites

Because class polygons smaller than 1 ha would be difficult to locate with confidence in the field, the final vegetation map was generalized to a minimum mapping unit of 25 pixels, or 1 ha. Final maps were plotted on translucent paper at a scale of 1:24,000 for overlay onto topographic maps of the study area. Mapwork and field surveys were used to identify five spatially distinct examples of each meadow type. Sample sites were located in the field with the aid of global positioning devices, 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.

We had originally intended to stratify meadows by size classes, but this was not possible because several of the M-types did not exist within a broad range of sizes. However, we did stratify by northern and southern portion of the ecosystem. There were some problems associated with the M4 classification in the Teton study area. Field investigations in late May indicated that areas mapped as M4 meadow types were in fact groves of aspen (*Populus tremuloides*) with dense herbaceous understories. These groves were not identifiable as such on the satellite imagery. Since the focus of this research was on non-forested montane meadows, and there is no close corollary to these groves in the Gallatin study area (aspen is nearly nonexistent in that area), the M4 type was eliminated from the Teton study area, and sampling proceeded in the remaining five meadow types. Thus we established 55 sampling sites for 1997 and 1998 (two study areas, six habitat types, five replicates per habitat type (except for M4's in Tetons)). See maps from year 1 progress report for details of site locations. In 1999 we established 8 new sites in the Tetons per mtype (total of 40 sites) and 5-6 new sites in the Gallatins (6 of all mtypes except M3 and M4, which had 5 new sites; total of 34 new sites).

Establishment of Sampling Sites

A single point was established at each of the sample sites. This point was located in an area reasonably typical (not anomalous) for each particular meadow, and in smaller meadow polygons was located near the center of the meadow so as to avoid edge effects. This point is the northwest corner of the 20 x 20 m plot used for botanical and biomass sampling. All 20 x 20 m plots were laid along cardinal directions for consistency. The 20 x 20 m plot was then established using four steps: a) The southwest corner was established by measuring 20 m due south from the northwest corner. b) The approximate location of the southeast corner was then located by measuring 20 m due east from the southwest corner. c) Triangulation was used to insure that the plot was square, and the southeast corner was located correctly. A hypotenuse of 28.3 m was measured from the northwest corner to the southeast. The southeast corner was established where the hypotenuse met the 20 m measurement from step two. d) The approximate location of the northeast corner was located by measuring 20 m due north from the southeast corner. Once again, triangulation was used to insure that the plot was square. The northeast corner was established at the point 20 m from the southeast corner and 20 m from the northwest corner. A 100 x 100 m plot was overlaid upon the 20 x 20 m plot, using the NW corner of the smaller plot as the center point. One of the four 50 x 50 m quadrants within the 100 x 100 m area was randomly selected to be used as the butterfly survey plot. Bird surveys were conducted in a 50 m radius circular plots using the midpoint of the 100 x 100 m plot and flags were used to mark edges of the circular plot in at least 3 of the cardinal directions. Observers surveying birds stood just off the center of the 100 x 100 m point, to avoid trampling the plants in the vegetation plots.

Each of the fifty-five 20 m by 20 m plots sampled was marked to facilitate relocation of plots in subsequent years. The northwest corner of each plot is marked with a 1.25 m steel or wooden post. All four corners of each plot were marked with a 0.3 m piece of buried steel rebar, which can be relocated with a metal detector. Because each plot was permanent and can be relocated, data can be used to track individual plants and species over time. A permanent and repeatable technique helps to insure that year to year species changes are indeed due to shifts in plant community composition rather than sampling error. The park service required that we remove the marker posts after the summer of 1999, so all of the posts have now been removed.

Biophysical and spectral field sampling

Biomass measurements were made in July for both Teton and Gallatin study areas. Measurements were scheduled to be coincident with satellite overpass days when possible. For each plot, three 0.20x0.50 m (0.1 m^2) quadrants were spaced at 10.0 m intervals along the northern edge of each 20x20 m plot. All aboveground green photosynthetically active vegetation within each quadrant was clipped, sorted by life form/category (grasses, forbs, and shrubs), placed in paper bags, and immediately weighed in the field using spring scales to the nearest 1.0 gram to determine "wet" weight. In the lab, bags were dried in a laboratory oven at 100° F for 48 hours, and weighed again to determine "dry" weight and percent moisture by life form.

Spectral reflectance readings were taken using an Analytical Spectral Devices (ASD) spectroradiometer, recording electromagnetic energy reflected by the surface over the range 0.3265 -1.05533 m (visible and near-infrared light) in 512 discrete spectral bands. Measurements were taken for each of the twenty 1x1 m quadrants used for botanical assessment. Ten spectroradiometer scans per quadrant were acquired and internally averaged by the system to determine spectral reflectance. All sites were sampled between 0900 and 1550 hours local solar time. A white reference calibration reading was made at the start of each plot to normalize all reflectance values to a common standard. Sites in Teton study area were sampled during the period July 2-7 (coincident with SPOT satellite image acquisition) and on July 20-23 for the Gallatin study area. SPOT multispectral satellite imagery were acquired by the SPOT satellite on July 12 for both Teton and Gallatin study sites, August 23 for Teton, and August 28 for Gallatin. Excessive cloud cover over both study sites during May, June, and September for both study areas in 1998 precluded satellite image acquisition for spring and late fall seasons. Satellite data acquisitions in 1998 were near-anniversary dates with data acquired for 1997, facilitating interannual comparison of vegetation condition and development.

Vegetation Sampling Techniques

Twenty 1m^2 quadrants were located systematically within each 20 x 20 m plot. The quadrants were arranged in four belt transects of five quadrants each. All belt transects ran west to east, and quadrates were 4 m apart. Field measuring tapes were laid in a grid-like fashion to insure correct locations of transects and quadrants. The first transect was located along the line between the northwest and northeast corners of the 20 x 20 m plot. The second, third and fourth transects were respectively located 5 m, 10 m, and 15 m south of the first transect. Along each transect, the northwest corner of the 1 m^2 quadrants were located at 3 m, 7m, 11 m, and 15 m from the east edge of the 20 x 20 m plot. The nested sampling design allows for detailed data collection within the 20 x 20 m plot, and the systematic layout insures that the quadrants are relocatable and sampling can be accurately repeated in subsequent years.

For each 1 m^2 , the aerial percent cover of all plant species was estimated during our July sampling period to derive a measure of plant species composition. Aerial cover estimations were conducted using a modified Daubenmire (1959) method in which estimations were made to the nearest percent. The combined cover of litter and bare ground was also estimated using estimated percent cover. This sampling technique is advantageous because it provides a measure of both species richness and species abundance. Percent cover provides valuable data since it can indicates both plant size and number of individuals.

All plants were identified to species in the field or given appropriate field names. Voucher specimens were collected for all species so that accurate identifications could be made. Species that were difficult to identify are being reviewed by botanists at the University of Kansas Herbarium where the vouchers will be housed. After the 1 m^2 plots were sampled, the entire 20 x 20 m plot and the 100 x 100 m plot were sampled for cover. This sampling provides us with data at 3 scales and with the middle scale (20 x 20 m), being of the actual pixel size of the remote sensing.

Species and Habitat Characterization in Sample Sites: birds and butterflies

Abundance data were collected for butterflies and birds in each of the sampling sites. Birds were surveyed between 0530-1030 hrs using point counts in 100 m diameter circular plots. Two observers were present for each 15 min survey. One point count was conducted at each site. Butterflies were surveyed between 0930-1630 hrs by two people netting for 20 minutes in each 50 x 50 m plot. Each butterfly was placed in a glassine envelope and at the end of the survey all individuals of each species were tallied and most were released. A subset of butterflies were taken as voucher specimens. In 1999, bird data were collected at each of the 1997-1998 and the 1999 sites on two dates (during June 1-July 16) in the Gallatins and the Tetons. Butterfly data were collected on two **dates** (during June 22-Aug. 8) in each region. Data collections in each of the two areas (Gallatin vs. Teton study area) alternated every two weeks to ensure that species with phenologically different emergence times or activity periods would be included in both data sets. All specimens were identified to species in the field or given appropriate field names. Voucher specimens of butterflies were collected so that accurate identifications could be made. Species that are difficult to identify are being reviewed by Steve Kohler, an authority on Montana lepidopterans. Voucher specimens are housed at Iowa State University.

Quality control

All sampling sites were permanently marked (see *Establishment of Sampling Sites*). At the start of sampling of each site, the entire crew of botanists, birders, lepidopterists, etc. discussed the species they expected to find and how they could be identified (see grant proposal for details of training). Sampling of each taxonomic group was always conducted with a partner to allow for discussion of each species identification and/or cover value. Voucher specimens were taken for all species of plants and many species of lepidoptera. Multiple vouchers were taken for problematic groups. Data collected were reviewed each day to make sure data sheets were legible and filled out properly. All data forms were copied and are being housed in multiple locations. Data are currently being entered and will be checked by a different person.

✦ RESULTS

Plant Community

Data from the 1998 field season were entered into a database and all measures of quality control were performed during the winter of 1998-1999. Results from the summer of 1999 are not yet available. Although there were differences between the Gallatins and the Teton sites, meadow types were generally fairly consistent in the composition by dominant species with M1 and M2s being dominated by *Salix spp* and *Carex rostrata*. M3 and M4 types were dominated by *Poa pratensis* and *Artemisia tridentata*, and M5 and M6 types being dominated by *Festuca idahoensis* and *Artemisia tridentata*.

Bird Community

We surveyed bird communities for three years using point counts. Overall, there were major differences in the bird community between regions. For example, there was 59% similarity between the Gallatins and the Tetons in 1997 and only 47% similarity in 1998. Results from Fisher's Exact tests comparing species composition between the Gallatins and Tetons indicated that all 5 meadow types were significantly different between regions in both years ($p<0.05$). Species composition was also compared between regions using a Kappa statistic. Three of 5 meadow types were statistically different between study areas in both years, but two of the meadow types had changed significance from the previous year. Our results indicate that similarity is not high between bird communities in the Gallatins and the Tetons, and it is difficult to use data from one of the study areas to predict the communities found in the 5 meadow types at the other area. Species composition in the most hydric meadow type was the only data set that could be accurately predicted in both study areas.

We also compared the accuracy of predicting the occurrence of a subset of 11 bird species in montane meadows using a combination of remotely sensed, landscape, and habitat data (Saveraid et al, in review). Meadow type, as determined from the remotely sensed data, was highly correlated with abundances of six of the 11 bird species. Abundances of generalist species were not strongly correlated with landscape variables or meadow type. However, abundances of six more specialized species were highly correlated with meadow type and landscape variables such as percent cover of willow (*Salix* spp.), graminoid, woody vegetation, sagebrush (*Artemisia* spp.), and graminoid and shrub biomass. The results from our study indicate that remotely sensed data are applicable for estimating potential habitats for bird species in the different types of montane meadows. However, for fine-scale information about species in specific sites or areas, we recommend the use of additional landscape and habitat data collected in the field.

Butterfly Community

Eighty-two species were found across both sampling areas during 1997 and 1998, and the species similarity between the two areas was 65%. Using species abundance data for each meadow type, canonical discriminant analysis and regression tree analysis were used to identify species that were important in distinguishing among meadow types. Fourteen species were important in distinguishing among meadow types in the Tetons and seven were important in distinguishing meadow types in the Gallatins (6 of the 7 species were common to both lists). These 14 species could be used to clearly separate each of the five meadow communities for both sampling areas. Our models of species-habitat relationships were then tested with canonical discriminant analysis and discriminant analysis (i.e., species data from the Gallatins were used to build a model that was tested on Teton data and vice versa). Predictability was not high using five habitat classes. However, if we collapsed the meadows into three classes rather than five, meadow type was up to 67% predictable overall. Meadow types at the two extremes of the gradient were 90-100% predictable while the mesic (middle gradient) meadow type was less easily predicted. Finally, butterfly species abundance and distribution were used to test predictability of meadow type in each region. Meadow type was predicted with a 92-96% accuracy in the Tetons (Borgognone et al. 1999), but the success rate was much lower in the Gallatins. We hypothesize that the small size of the meadows in the Gallatin ecosytem (see below) is making predictability much more difficult as compared to the Teton ecosystem.

FRAGSTATS analysis

FRAGSTATS spatial analysis program was applied to the ArcInfo GIS coverage of meadow habitat classifications to calculate parameters such as meadow size, distance to next meadow of the same type, and average distance to all meadows of a specific type. Preliminary results show that meadows in the Tetons are 10 times larger on average than meadows in the Gallatins (132.8 ha versus 12.9 ha) and that landscape context may have significant effects on bird and butterfly species distribution patterns (possibly explaining some of the differences between the sampling regions).

Wetlands

Our technique for finding wetland communities (M1 and M2 meadows) has been greatly improved by the research methods we have developed during our study. Using our remotely sensed data and previously collected vegetation data, we developed a new procedure for identifying wetlands using average wetland values. Using these techniques, we identified 1,250 hectares of M1 wetland meadows and 1,711 hectares of slightly drier M2 wetland meadows in Grand Teton National Park (Kindscher et al., 1998).

✦ PRESENTATIONS

1999 Debinski, D.M., M.G. Borgognone, M.E. Jakubauskas, and K. Kindscher. (poster) Testing the predictability of species-habitat relationships in a butterfly community. Predicting Species Occurrences: Issues of scale and accuracy, Snowbird, UT, Oct. 18-22.

1999 Saveraid, E. H., D.M. Debinski, M.E. Jakubauskas, and K. Kindscher. (poster) The accuracy of using satellite imagery to predict meadow types and bird communities in the Greater Yellowstone Ecosystem. Predicting Species Occurrences: Issues of scale and accuracy, Snowbird, UT, Oct. 18-22.

1999 Debinski, D.M. The science of global climate change: a symposium on the state-of-the-science. Sponsored by the Center for Global and Regional Environmental Research and the Iowa Division of the United Nations Association – USA. Iowa City, IA, March 5.

1999 Debinski, D.M., M.E. Jakubauskas, and K. Kindscher. Modeling spatial and temporal dynamics of montane meadows and biodiversity in the Greater Yellowstone Ecosystem. U.S. EPA Ecological Indicators meeting, San Francisco, CA, April 6-9 (published abstract).

1999 Jakubauskas, M.E., D.M. Debinski, and K. Kindscher. Montane meadows as indicators of environmental change. U.S. EPA Ecological Indicators meeting, San Francisco, CA, April 6-9. (published abstract).

1998 Debinski, D.M., M.E. Jakubauskas, and K. Kindscher. Modeling spatial and temporal dynamics of montane meadows and biodiversity in the Greater Yellowstone Ecosystem U.S. EPA Ecological Indicators meeting, Las Vegas, NV, Feb. 2-5 (published abstract).

1998 Debinski, D.M., E.H. Saveraid, M.E. Jakubauskas, and K. Kindscher. (poster) Butterfly species richness relative to landscape context in montane meadows. Thirteenth Annual Conference of the International Association of Landscape Ecologists, East Lansing, MI, March 17-21 (published abstract).

1998 Debinski, D.M., E.H. Saveraid, M.E. Jakubauskas, and K. Kindscher. Landscape effects on butterfly community structure. Ecological Society of America Annual meeting, Baltimore, MD, Aug 2-6 (published abstract).

1998 Jakubauskas, M.E., K. Kindscher, and D.M. Debinski. Relationships between biophysical factors and spectral reflectance patterns of Greater Yellowstone montane meadows. Association of American Geographers Annual Meeting, Boston, MA, Mar. 25-29 (published abstract).

1997 Debinski, D.M. and E. Saveraid. The influence of patch size and landscape context on butterfly diversity in montane meadows of the Greater Yellowstone Ecosystem. Society of Conservation Biology meeting, symposium entitled: Considerations of Reserve Design: Core Reserves, Buffer Zones, and Connecting Habitat. June 6-9, Victoria, B.C. (published abstract).

1997 Kindscher, K., A. Fraser, M. Jakubauskas, and D.M. Debinski. Vegetation differences in remotely-sensed wetlands of the Grand Teton National Park. Society of Wetland Scientists, Bozeman, MT, June 1-6 (published abstract).

✦ FUTURE ACTIVITIES

Our work is approximately three-quarters completed at this point.

Analysis of spectral data is continuing along several thrusts. Close-range hyperspectral radiometer data are being analyzed to determine relationships between biomass and spectral reflectance in montane meadows. Toward this end, we are exploring the use of derivative analysis to separate the relative contributions of forbs, grasses, and shrubs to the composite spectral reflectance for a plot. Interannual comparisons between the 1997 and 1998 spectroradiometer and biomass data will be conducted to refine measures of vegetation condition and development. Analysis of the satellite data will address several research directions: biophysical remote sensing (modeling relationships between biophysical data and spectral reflectance), landscape heterogeneity (as quantified by first-order texture analysis of single- and multi-date satellite imagery), and predictive modeling of vegetation communities through integrated analysis of satellite and GIS data. Toward these ends, processing is ongoing to georeference the satellite data, convert it to reflectance values, and perform topographic normalization to account for differing solar incidence angles. Texture analysis will be initiated, starting with the 1994 Gallatin data set, evaluating relationships between plant and animal abundance and diversity and seasonal and interannual variability in local landscape heterogeneity. Geographic information systems-based models of environmental factors (annual insolation, exposure, potential evapotranspiration, phenological variability) potentially relating to plant and animal diversity/abundance will be developed during winter 1998-99. Correlation-and-regression-tree (CART) analysis of GIS and remote sensing data will begin during spring 1999 as part of our efforts to develop predictive maps for directing fieldwork in summer 1999.

Data for birds and butterflies for both 1997 and 1998 have been entered and verified. Bird data for 1999 are entered and verified. Plant and butterfly data for 1999 are currently being entered and should be completed by the end of December. Quality control of the data will follow. Data summaries and statistics comparing meadow types will be conducted this winter. In addition, a data matrix of species and functional and ecological traits is being compiled.

The final year of the grant will be spent primarily on data analysis and writing of manuscripts.

✦ LITERATURE CITED

Daubenmire, R.F., 1959, Canopy coverage method of vegetation analysis. Northwest Science 33:43-64.

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Kindscher, K., A. Fraser, M.E. Jakubauskas, and D.M. Debinski. 1998. Identifying wetland meadows in Grand Teton National Park using remote sensing and average wetland values. Wetlands Ecology and Management 5:265-273.

Saveraid, E. H. 1999. Using satellite imagery and landscape variables to predict bird communities in montane meadows of the Greater Yellowstone Ecosystem. M.S. Thesis, Ecology and Evolution Biology Program, Iowa State University, Ames, Iowa.