Research Article

GIS-based Indicators of Montana Grasshopper Communities

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Abstract

We evaluated two digital data sources that might be helpful in characterizing grasshopper habitat using plant and grasshopper species composition data collected at 128 sites in three areas of Montana. A GIS was used to associate each sampling site with Omernik's ecoregions and the Montana State Soil Geographic Database (MTSTATSGO). Detrended Correspondence Analysis (DCA) and statistical analyses were used to test for correlations among grasshopper species, available water capacity, and soil permeability across sampling areas and ecoregions. Four grasshopper species were correlated with soil permeability and six were correlated with available water capacity. MTSTATSGO plant cover percentages did not correlate with cover measured in the field, indicating inadequate resolution for the scale of this study. Ecoregions were useful in distinguishing grasshopper community gradients across Montana, from mountains to plains. These georeferenced data should be considered as input for grasshopper forecasting and decision-making models. Our results show how GIS can be used to evaluate relationships between digital data sets and ecological data gathered in the field.

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1 Introduction

Interest in geographic information technologies has been increasing rapidly in recent years. Applications of GIS to ecological problems have ranged from conservation and habitat concerns (e.g. Jones et al 1997, Van Manen and Pelton 1997) to pest monitoring (e.g. Lefko et al 1998). The use of GIS to combine digital data layers, which are inexpensive and readily available, with field data is a potentially powerful approach to a variety of ecological questions. In this paper, we examine the use of GIS and digital map data for categorizing grasshopper habitats in Montana.

On the rangelands of the western United States, grasshoppers (Orthoptera: Acrididae) destroy more than 13 million metric tons of forage each year (Hewitt and Onsager 1983). However, losses to grasshoppers are extremely variable over both time and space. The amount of damage depends on overall abundance, the species present, and their proportions (Anderson and Wright 1952, Davis et al 1992), factors which vary with vegetation and local habitat (Anderson 1964, Capinera and Sechrist 1982, Kemp 1992a, Kemp et al 1990, Quinn et al 1991). In addition, the combined effects of weather, soil conditions, vegetation, and previous year's abundance determine whether grasshopper populations will reach economically damaging densities (Capinera and Horton 1989; Kemp 1987, 1992b).

The native habitats that most frequently have a favorable combination of these factors are not yet known; nor is it known where those habitats are located within the landscape of Montana. Identification of these areas would (1) focus grasshopper survey and management efforts on critical habitats; (2) be useful in assessing the risk of losses, and calculating premiums, for a federal rangeland grasshopper insurance program (Skold and Davis 1995); and (3) help to clarify the mechanisms that regulate grasshopper populations, since grasshopper abundance is closely linked to habitat type. Ecoregions (Omernik 1987, 1995) present a habitat classification scheme that may aid in identifying areas where damaging grasshopper densities are likely to occur.

Digital vegetation and soil maps are inexpensive alternatives to field surveys for habitat information. These data, available at various resolutions, provide environmental variables which may be useful for grasshopper habitat classification, but only if the data accurately describe the field conditions important to community composition. To evaluate two such digital data sources, we used a GIS to link georeferenced habitat information with plant and grasshopper species data collected in the field. Our objectives were to determine (1) whether ecoregions can be used as indicators of grasshopper communities on a state-wide scale and (2) whether the Montana State Soil Geographic Data Base (MTSTATSGO) is an indicator of grasshopper communities and their habitats on a state-wide scale. Positive outcomes for these objectives may promote use of GI technologies for grasshopper decision-support systems, pest management tools, and ecological assessments.

2 Methods

Studies of grasshopper ecology range in scale from the microenvironment around an individual plant to multi-state geographic regions. Analyses of spatially-patterned phenomena must be conducted at the proper scale to ensure that the correct context and constraints are examined. Unfortunately, the term "scale" means different things to different scientists. Ecologists use scale to measure spatial and sometimes temporal size (Allen and Hoekstra 1992), whereas geographers use scale to refer to the ratio between an object's size on a map and actual size on the ground. In this study, "scale" is used in the ecological sense to refer to spatial extent and "resolution" refers to the amount of detail captured by the data. Thus, small-scale concepts apply to small areas of land, such as a single site, and large-scale concepts apply to larger areas such as multiple watersheds, a state, or a multi-state ecological region.

2.1 Site Selection

Plant and grasshopper communities were sampled at 80 sites near Jordan, Montana, 22 sites in the Madison river area of Montana, and 26 sites near Big Timber, Montana, during 1993 (Figure 1a). At the Jordan sites, grasshoppers were sampled twice: the first set of samples were collected during the first two weeks of June and the second set of samples were taken during the second and third weeks of August. The Madison and Big Timber sites were sampled once during mid-August. To maintain consistency, the data from the first sampling dates at Jordan were not used.

The climax vegetation types represented by the sampling areas were determined from Ross and Hunter (1976), who define the climax plant community as that which develops under the prevailing climatic and soil conditions, in the absence of disturbance. The sites near Jordan were chosen in three different vegetation types (Figure 1b) to determine the influence of the plant community on grasshopper community composition at small scales (within a sampling area). The vegetation types were arbitrarily designated A, B, and C; site numbering and vegetation type descriptions are given in Table 1.

The latitude and longitude of each site was obtained with a Magellan global positioning system (GPS) receiver, accurate to ±12 m horizontal distance. Topographic maps were used to find the altitude of each site for input into the receiver. The location of each sampled site was the average of 100 point estimates made for the site with the GPS receiver.

Table 1 Vegetation types represented by grasshopper sampling areas (from Ross and Hunter 1976).

Sampling Area/ Vegetation Type	Site Numbers	Precip. Zone	Dominant Vegetation	Soil Texture
Jordan				
A	101-130	10-14″	wheatgrass, needlegrass, little and big bluestem, silver sagebrush	silty
B	201-225	10-14″	wheatgrass, needlegrass, little bluestem, big sagebrush	silty or clayey
C	301-325	10-14″	wheatgrass, green needlegrass, wildrye, big sagebrush, greasewood	dense clay, clayey or saline
Madison (D)	401-422	10-14″ or 15-19″	fescues, bluebunch wheatgrass, needleandthread, basin wildrye	silty or clayey
Big Timber (E)	501-526	10-14″, 12-14″, or 15-19″	wheatgrass, needlegrass, big sagebrush, fescues, prairie junegrass	silty, clayey, or shallow clay

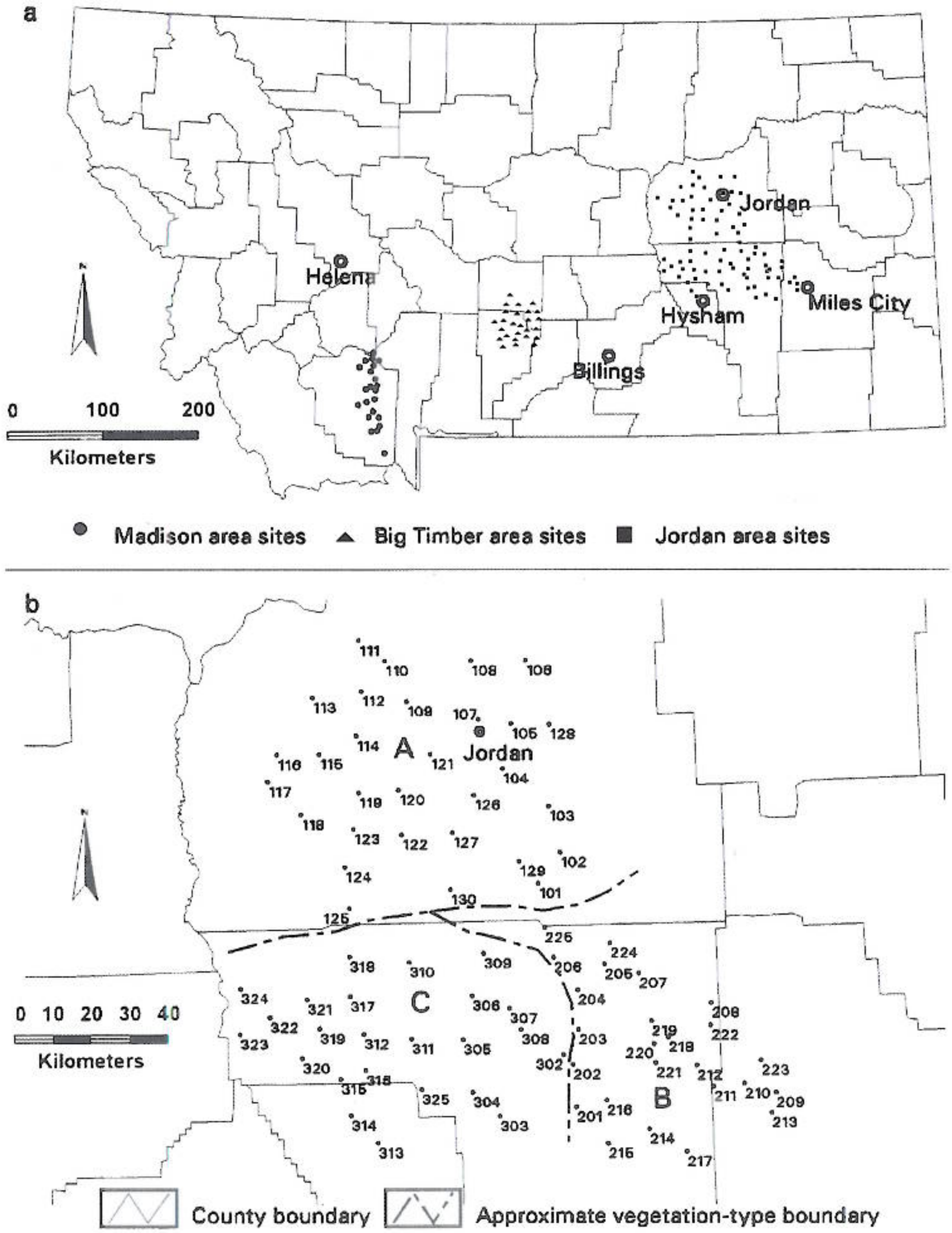

Figure 1 (a) Sampling sites for 1993 with Montana county boundaries; (b) Sites near Jordan, Montana. Solid lines represent county boundaries, while dashed lines represent the boundaries of climax vegetation types A, B, and C. Sites located in vegetation type A have silty soils and are dominated by wheatgrass and needeleandthread; vegetation type B has silty or clayey soil with wheatgrass and green needlegrass; type C has dense clayey or saline soil with wheatgrass, green needlegrass and wildrye (Ross and Hunter 1976).

2.2 *Vegetation Sampling*

The plant community was sampled by examining the vegetation contained in five 0.10 m^2 Daubenmire (1959) frames at each site. The percent cover of bare ground, leaf litter, and individual species were recorded. Total cover, tallest plant height, and modal plant height were also measured. The data were averaged over the five frames. Nine plant species and genera with the highest mean percent cover and frequencies at each of the sampling areas were selected for correlation testing: *Agropyron* spp., *Artemisia* spp., *Carex* spp., *Festuca idahoensis* Elmer, *Koeleria cristata* Pers., *Phlox hoodii* Rich., *Poa* spp., and *Stipa* spp. The percent cover for a genus is the sum of the percent cover values of all species collected for that genus.

2.3 *Grasshopper Sampling*

Grasshoppers were collected via sweep nets at the same sites where plant sampling was conducted; grasshopper data were missing for site 105. The number of individuals in the first through fifth developmental stages (instars), adult males and adult females were recorded for each grasshopper species collected in 200 sweeps at each site. Sweeps were taken between 0930 and 1600 h when cloud cover was less than 15% and winds were less than 25 kmh^{-1}, with each sweep covering a low 180 degree arc through vegetation with a net. Crickets were counted and included in the data set.

The sum of individual grasshoppers of all ages for each species and the proportion that each species contributed to the local community were calculated for each site. Thirteen species with the highest frequencies and average proportions of the community at each of the sampling areas were selected for correlation analyses (Table 2).

Table 2 Grasshopper species names, codes used for analyses, and subfamily classifications* for collections made at sites in Montana, 1993.

Code	Species	Subfamily*
CLAVA	*Aeropedellus clavatus* (Thomas)	G
COLOR	*Amphitornus coloradus* (Thomas)	G
CORAL	*Xanthippus corallipes* Haldeman	O
DELIC	*Psoloessa delicatula* (Scudder)	G
DEORU	*Ageneotettix deorum* (Scudder)	G
ELLIO	*Aulocara elliotti* (Thomas)	G
GLADS	*Melanoplus gladstoni* Scudder	M
INFAN	*Melanoplus infantilis* (Scudder)	M
KIOWA	*Trachyrhachys kiowa* (Thomas)	O
OBSCU	*Opeia obscura* (Thomas)	G
PACKA	*Melanoplus packardii* Scudder	M
PELLU	*Camnula pellucida* (Scudder)	O
SANGU	*Melanoplus sanguinipes* (Fabricius)	M

*"G" refers to the subfamily Gomphocerinae, "M" refers to the subfamily Melanoplinae, and "O" refers to the subfamily Oedipodinae.

2.4 GIS Processing

The location of each sampling site was converted to decimal degrees in SAS (SAS 1985) and used to generate georeferenced databases called "coverages". All coverages were manipulated using version 6.1.1 of the ARC/INFO geographic information system (ESRI 1992). Locational data for the three sampling areas were treated in three separate coverages, each of which was converted to an Albers Conic Equal Area map projection.

2.4.1 Ecoregions

There are a number of ecoregion maps available in digital form; the most widely known is perhaps Bailey's (1980). Omernik's (1987) ecoregion map was used in this study because of its finer level of detail. This map was compiled for the conterminous United States at a scale of 1:7,500,000 from potential vegetation, land use, topography, and soil maps. Ecoregions within the boundary of Montana were extracted using a coverage of state boundaries (USGS-ESIC 1991) and overlaid with each of the sample site coverages (Plate 5, see plate section).

2.4.2 Soil Data

The State Soil Geographic Data Base for Montana (MTSTATSGO) contains generalized plant and soil data at a map scale of 1:250,000 (USDA 1991). This coverage was projected into an Albers Conic Equal Area map projection and intersected with each of the sampling area coverages. The resulting coverages included the sampling points and the number of the MTSTATSGO map unit in which each point lies (Plate 6, see plate section). This map unit identification number (MUID) was later used to determine the physical attributes of each sampling site by extracting specific MTSTATSGO attributes for the MUIDs which overlap the Jordan, Madison, and Big Timber sampling areas.

2.5 Data Analysis

Species proportions and percentages were first analyzed using detrended correspondence analysis (DCA). DCA is a nonlinear, weighted averaging method of measuring the variance among species and site data in a single analysis, in which sites and species are ordered along four axes according to their similarities to each other (ter Braak 1988). The result is a list of eigenvalues for each species and site, representing roughly the proportion of the variance accounted for by each ordination axis. Each axis represents a gradient in an ecological factor, and low eigenvalues indicate little difference in that factor among the sites and species ordinated, while high eigenvalues indicate large differences.

Using the computer program CANOCO (ter Braak 1988), initial DCA runs were conducted on all sites and variables in each data set. For the grasshopper data, site 307 was omitted from a second DCA to allow greater separation among the remaining sites. Each DCA results in two sets of axis scores, one for species and one for sites, although eigenvalues are the same for both sets of scores. Axis 1 and 2 scores resulting from each final DCA were input into SAS (SAS 1985) programs to produce graphs of the ordinated sites and species. The results were plotted with a different symbol for each ecoregion and visually inspected; little overlap among symbols indicates that high eigenvalues result from differences in species composition.

2.5.1 *Ecoregions*

To determine whether Omernik's ecoregions for Montana differ in grasshopper species composition, DCA output was visually inspected, as described above. This test examines the validity of using Omernik's ecoregions to characterize Montana grasshopper habitats. For example, are ecoregions 42 and 43 (Plate 5) distinct from one another in terms of grasshopper community composition? If the ecoregions do not cluster separately in the DCA plot, there is support for dissolving ecoregion boundaries with respect to grasshopper habitat characterization. Differences between ecoregion 17 and the other ecoregions could not be tested because only one sampling site was located in ecoregion 17.

2.5.2 *Grasshopper Densities*

To test for differences in mean grasshopper densities between each of the ecoregions, the mean number of grasshoppers per unit area was calculated for each ecoregion. Multiple comparisons of the resulting means were performed with ANOVA using the Tukey HSD test.

2.5.3 *Soil Data*

The MTSTATSGO data base includes a number of tabular data files which contain information about the soil and vegetation within each map unit (Plate 6). Because each map unit may encompass up to 21 components (soil series), each component is comprised of several soil layers, and components are not spatially referenced, there is no one map unit value for a given attribute. To reduce this one-to-many relationship and correlate MTSTATSGO attributes with plant and grasshopper community data, the weighted average of each soil attribute was calculated to estimate one value for the entire mapping unit. The data were exported to ASCII files and formatted using SAS (SAS 1985).

Because the permeability (PERM) and available water content (AWC) of soil influence grasshopper hatching and oviposition (Hewitt 1985), these soil attributes were chosen from the Montana STATSGO database as possible indicators of grasshopper community composition. For each of these attributes, STATSGO lists a maximum and minimum value for each soil layer. The AWC values for each layer within a meter of the soil surface were averaged by adding the minimum and maximum values together and dividing by two. The result was multiplied by the thickness of the soil layer, and the layer values were summed over the soil profile, giving the weighted AWC (in inches of water per inch of soil) for each soil component. The mean of these component values was calculated in SAS (SAS 1985) using PROC MEANS, with the percent of the map unit covered by each component used to weight the values. The soil permeability rate (PERM, in inches per hour) was weighted similarly, except layer values were summed to get a mean PERM value for each component, because the water available to a plant is cumulative over soil layers.

To test for correlations between MTSTATSGO soil attributes and grasshopper species composition, we conducted Spearman rank correlations between AWC and PERM values and the percent cover of selected grasshopper species (Table 2). SAS (SAS 1985) was used to perform the correlations and to calculate the test statistic t. The P-value for each value of t was determined in MSUSTAT (Lund 1991). All statistical results were interpreted at the $\alpha = 0.05$ level.

To determine whether MTSTATSGO soil attributes differ among the ecoregions, AWC and PERM values for each site were merged with ecoregion numbers and non-parametric statistical tests were performed using the NPAR1WAY procedure in SAS (SAS 1985). If the *P*-value of the Kruskal-Wallis test output by SAS was significant at the $\alpha = 0.05$ level, then Wilcoxon tests on AWC and PERM values were performed between pairs of ecoregions. Differences in MTSTATSGO attributes among the three sampling areas were tested in a similar manner.

The MTSTATSGO attribute data include the percent of total plant production attributed to a given plant species for each map unit component. Percentages for selected plant species and genera (listed above in Section 2.2) were weighted by the percent of the map unit covered by each component. The mean of the component values was used as the map unit average. To test for correlations between MTSTATSGO plant production data and plant cover data collected at field sites, Spearman rank correlations were performed.

3 Results and Discussion

3.1 *Ecoregions*

3.1.1 *Grasshopper Species Composition*

The DCA on grasshopper species resulted in very high eigenvalues (>1.0 for the sum of the first two axes), indicating large differences in grasshopper community composition among ecoregions. Figure 2 graphs the DCA output for sites, coded by ecoregion.

Sites in ecoregions 42 (Northwestern Glaciated Plains) and 43 (Northwestern Great Plains) had generally low axis 1 scores, indicating a gradient on axis 1 from plains sites to mountain sites (see Plate 5). Ecoregion 43 appears to be a transitional ecoregion between foothill prairies and glaciated plains (Omernik 1987), having some attributes of both the mountains and plains to which the region is adjacent, as sites in 43 overlap those in ecoregions 16 and 42 (Figure 2). Thus, while the ecoregions differ in grasshopper community composition, there is overlap among ecoregions in the species present and their proportions. This is consistent with the fact that the Great Plains ecoregions, for example, can be considered subsets of a larger ecological region (Bailey 1980) and thus share similar climatic processes and species pools. There were not sufficient data in this study to test whether ecoregion 16 is a transitional ecoregion between the high mountains of ecoregion 17 (Middle Rockies) and the plains ecoregions (i.e. ecoregions 42 and 43 in Plate 5).

In Figure 2, sites in ecoregion 43 that overlap ecoregions 16 and 42 are not consistently closer to the ecoregion boundaries than are other sites. This indicates either the lack of an ecotone effect, in which there is a transition of species at the boundary of two habitat types, or insufficient resolution at the ecoregion level to detect such an effect. There may, however, be an ecotone effect at a larger scale, such that the transition occurs over multiple ecoregions, rather than at the edge of any pair of ecoregions. While ecologists generally use the term 'ecotone' to refer to smaller scale species changes, ecoregion 43 may be considered one very large ecotone based on the data analyzed here.

Grasshopper communities within ecoregions 16 and 42 are relatively homogeneous, as indicated by their close ordination (Figure 2). Thus, Omernik's ecoregions are useful both in distinguishing between foothill and plains grasshopper

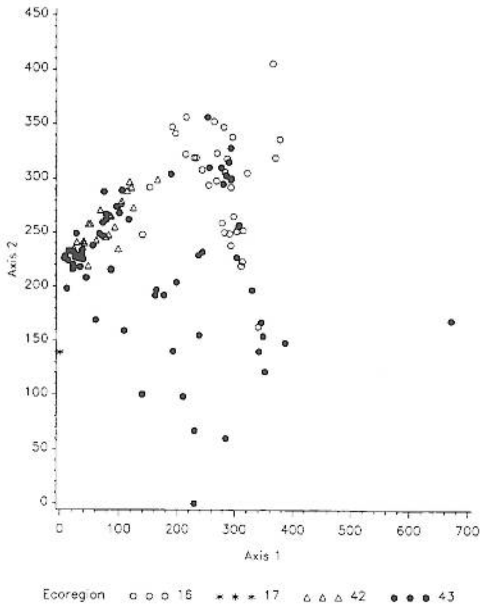

Figure 2 Results of detrended correspondence analysis based on grasshopper species composition. Ecoregion 16 is Montana Valley and Foothill Prairies, 17 is Middle Rockies, 42 is Northwestern Glaciated Plains, and 43 is Northwestern Great Plains.

communities at a state-wide scale (objective 2) and in capturing similarities among communities at a smaller scale. Ecoregions could be used to partition grasshopper survey data, collected annually at numerous sites across Montana, into subsets comprised of a single ecoregion with relatively similar habitat types. Further study is needed to demonstrate whether grasshopper communities within individual ecoregions exhibit similar population dynamics. The extent to which ecoregions capture habitat differences for other herbivore insect communities will be determined by their sensitivity to spatial patchiness (Kemp 1992a, Allen and Hoekstra 1992) and the scale at which the insects use their environment (Wiens 1989).

3.1.2 Grasshopper Densities

The results of tests for differences in grasshopper densities among the ecoregions and vegetation types are given in Table 3. Mean grasshopper numbers were significantly different between ecoregions 16 and 43 and between Jordan and both the Big Timber and Madison areas. In the Big Timber area, sites in ecoregion 16 were not significantly different from sites in ecoregion 43 with respect to grasshopper abundance (P-value = 0.84), so distinguishing between ecoregions is not meaningful with respect to grasshopper densities at that sampling area. Thus, while Omernik's ecoregions are capable of distinguishing among some habitats which support differing grasshopper densities in Montana (objective 1), differences were not found among all ecoregions.

Grasshopper abundances differed in all tests that included sites in ecoregion 43 (Northwestern Great Plains) at Jordan. The combination of grassland and grazing land with open hills and tablelands in ecoregion 43 (Omernik 1987) supports lower grasshopper densities than the other ecoregions. The basis for the difference in

Table 3 Results of Tukey's HSD tests for differences in grasshopper abundance among ecoregions and sampling areas of Montana, 1993. Vegetation types ("Veg. Type") are listed in Table 1.

(I) Ecoregion	(J) Ecoregion	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
16	42	18.58	24.96	0.738	−40.66	77.82
	43	56.37*	19.33	0.012	10.50	102.24
42	43	37.79	22.22	0.209	−14.95	90.53
(I) Veg. Type	**(J) Veg. Type**	**Mean Difference (I-J)**	**Std. Error**	**Sig.**	**95% Confidence Interval Lower Bound**	**95% Confidence Interval Upper Bound**
A	B	4.69	25.04	1.000	−64.67	74.04
	C	62.21	25.04	0.101	−7.15	131.56
	D	−25.05	26.30	0.876	−97.92	47.81
	E	−34.16	24.77	0.642	−102.78	34.46
B	C	57.52	26.15	0.187	−14.92	129.96
	D	−29.74	27.37	0.813	−105.55	46.07
	E	−38.85	25.90	0.564	−110.59	32.89
C	D	−87.26*	27.37	0.015	−163.07	−11.45
	E	−96.37*	25.90	0.003	−168.11	−24.63
D	E	−9.11	27.13	0.997	−84.25	66.03

Based on observed means.

*Mean difference is significant at the $\alpha = 0.05$ level.

grasshopper abundance with ecoregion 42 (Northwestern Glaciated Plains) is unclear but could be due to soils (Isely 1938, Quinn et al 1991), plant species composition (Anderson 1964, Kemp et al 1990), precipitation and temperature regimes (Capinera and Horton 1989, Edwards 1960, Kemp and Cigliano 1994), the previous year's grasshopper densities (Kemp 1992b), or disturbance (Fielding and Brusven 1993).

Between ecoregions 16 and 42, grasshopper species composition changes while overall abundance does not (Figure 2, Table 3). This indicates replacement of species across ecoregions 16 and 42, such that the geographic range of a species is determined by habitat characteristics (expressed by ecoregion), while yearly densities are constrained by weather patterns and resource conditions.

3.2 Species Correlations

Axes 1 and 2 of DCA site scores for the grasshopper data set are correlated (P-value = 0.0096), which presents problems in interpreting which factors contribute to the grasshopper community ordination. One disadvantage of DCA is that isolating the causes of such correlations is difficult. Both axes may be ordinating on a similar environmental variable, but it was not possible to confirm this by examining the raw data. This could result if axis 1 and 2 are both correlated with the same environmental or plant variables. Hence, the correlations between grasshopper axes and the geographically referenced map data may not be reliable (Gauch 1982).

3.3 Soil Data

3.3.1 Grasshopper Species Composition

There were significant negative correlations between AWC and *Ageneotettix deorum*, *Amphitornus coloradus*, *Melanoplus infantilis*, *Melanoplus packardii*, and *Melanoplus sanguinipes*; and between PERM and *Xanthippus corallipes*. AWC was positively correlated with *Melanoplus gladstoni* and PERM was positively correlated with *Ageneotettix deorum*, *Aulocara elliotti*, and *Melanoplus infantilis* (Table 4). Because multiple correlations were performed, one or more of these significant correlations may be spurious, and results should be interpreted accordingly. Correlations between

Table 4 Spearman rank correlations on STATSGO soil attribute values and proportions of grasshopper species. "AWC" is the average available water capacity and "PERM" is the average soil permeability rate for the mapping unit in which a given site is located. Grasshopper species codes are listed in Table 2.

Correlation on	N	r_s	t	*P*-value*
AWC by PERM	31	0.021	0.1131	0.9108
AWC by CLAVA	38	−0.148	−0.8875	0.3806
AWC by COLOR	40	−0.429	−2.6288	0.0122[2]
AWC by CORAL	69	0.191	1.5625	0.1228
AWC by DELIC	71	−0.006	−0.0498	0.9604
AWC by DEORU	52	−0.331	−2.3348	0.0236[2]
AWC by ELLIO	22	−0.049	−0.2191	0.8286
AWC by GLADS	62	0.269	2.0810	0.0416[2]
AWC by INFAN	76	−0.315	−2.7057	0.0084[1]
AWC by KIOWA	71	−0.056	−0.4652	0.6432
AWC by OBSCU	61	−0.061	−0.4685	0.6412
AWC by PACKA	35	−0.390	−2.2282	0.0246[2]
AWC by PELLU	19	−0.240	−0.9860	0.3372
AWC by SANGU	97	−0.453	−4.4033	0.0000[1]
PERM by CLAVA	38	0.037	0.2220	0.8256
PERM by COLOR	40	0.183	1.1271	0.2666
PERM by CORAL	69	−0.339	−2.7695	0.0086[1]
PERM by DELIC	71	−0.161	−1.3369	0.1856
PERM by DEORU	52	0.302	2.1312	0.0378[2]
PERM by ELLIO	22	0.464	2.0464	0.0534
PERM by GLADS	62	0.002	0.0155	0.9876
PERM by INFAN	76	0.362	3.1077	0.0026[1]
PERM by KIOWA	71	0.017	0.1412	0.8882
PERM by OBSCU	61	−0.242	−1.8569	0.0682
PERM by PACKA	35	−0.256	−1.4675	0.1512
PERM by PELLU	19	−0.251	−1.0308	0.3162
PERM by SANGU	97	0.150	1.4617	0.1470

**P*-value was calculated for a two-tailed *t* distribution.

[1] Significant at $\alpha = 0.01$ level.

[2] Significant at $\alpha = 0.05$ level.

Table 5 Kruskal-Wallis test results for MTSTATSGO soil attributes and ecoregion. Wilcoxon scores are rank sums and average scores were used for ties.

Wilcoxon Scores for Available Water Capacity (AWC)

Ecoregion	N	Sum of Scores	Expected Under H_o	Std Dev Under H_o	Mean Score
43	70	4163.00	4515.00	207.815906	59.471429
42	23	2458.00	1483.50	160.278155	106.869565
16	34	1542.50	2193.00	184.382268	45.367647
17	1	92.50	64.50	36.755102	92.500000

Kruskal-Wallis Test (Chi-Square Approximation)
CHISQ = 41.341, DF = 3; Prob > CHISQ = 0.0001*

Wilcoxon Scores for Permeability Rate (PERM)

Ecoregion	N	Sum of Scores	Expected Under H_o	Std Dev Under H_o	Mean Score
43	70	3039.00	4515.00	207.815906	43.414286
42	23	1468.00	1483.50	160.278155	63.826087
16	34	3635.50	2193.00	184.382268	106.926471
17	1	113.50	64.50	36.755102	113.500000

Kruskal-Wallis Test (Chi-Square Approximation)
CHISQ = 69.577, DF = 3; Prob > CHISQ = 0.0001*

* Significant at $\alpha = 0.01$ level.

economically important species (such as *A. deorum*, *M. packardii*, and *M. sanguinipes*) and the MTSTATSGO soil data suggest that this digital map data set will be especially useful as an indicator of habitats where these species are likely to reach damaging population levels.

3.3.2 *Ecoregions*

Significant differences were found for both AWC and PERM over the four ecoregions (Table 5). Subsequent pairwise tests found significant differences between values of both AWC and PERM for all pairs of ecoregions tested (*P*-values ranged from 0.0001 to 0.0437). Thus, ecoregions capture variability in soil characteristics as reported in the MTSTATSGO data base.

3.3.3 *Sampling Areas*

Significant differences were identified among the sampling areas for both AWC and PERM (Table 6). Pairwise tests found differences between values of AWC for sampling area A with areas C, D, and E (*P*-values were 0.0001, 0.0010, and 0.0001, respectively); and for area B with areas C, D, and E (*P*-values were 0.0017, 0.0010, and 0.0001, respectively). Values of PERM were different for all pairs of sampling areas (*P*-values ranged from 0.0001 to 0.0338).

Table 6 Kruskal-Wallis test results on MTSTATSGO soil attributes and sampling area. Wilcoxon scores are rank sums and average scores were used for ties.

Wilcoxon Scores for Available Water Capacity (AWC)

Area	N	Sum of Scores	Expected Under H_o	Std Dev Under H_o	Mean Score
A	30	2671.00	1935.00	176.843635	89.0333333
B	25	2037.50	1612.50	165.502434	81.5000000
C	25	1228.00	1612.50	165.502434	49.1200000
D	22	1066.00	1419.00	157.499813	48.4545455
E	26	1253.50	1677.00	167.958709	48.2115385

Kruskal-Wallis Test (Chi-Square Approximation)
CHISQ = 32.137, DF = 4; Prob > CHISQ = 0.0001*

Wilcoxon Scores for Permeability Rate (PERM)

Area	N	Sum of Scores	Expected Under H_o	Std Dev Under H_o	Mean Score
A	30	1663.00	1935.00	176.843635	55.433333
B	25	1171.50	1612.50	165.502434	46.860000
C	25	616.00	1612.50	165.502434	24.640000
D	22	2532.00	1419.00	157.499813	115.090909
E	26	2273.50	1677.00	167.958709	87.442308

Kruskal-Wallis Test (Chi-Square Approximation)
CHISQ = 88.103, DF = 4; Prob > CHISQ = 0.0001*

*Significant at $\alpha = 0.01$ level.

Because of the one-to-many relationship between soil layers and map units in the STATSGO data, a weighted average was calculated for each soil attribute and MUID. This generalized average may not represent the true AWC or PERM value for any one location in the MUID, and thus analyses based on average soil attributes must be interpreted with caution. Because our analysis sought to examine soil attributes among ecoregions and sampling areas on a comparative basis, without regard to the actual values, we were not concerned by the fact that the weighted average may not represent true soil conditions.

3.3.4 Plant Cover

No significant correlations were found between MTSTATSGO plant production values and plant cover as measured at sampling sites. The lack of correlations indicates that MTSTATSGO plant data do not associate closely with plant cover on the ground. The STATSGO values may be too coarsely estimated for prediction of plant community composition, even at a statewide scale.

The STATSGO data are compiled by generalizing soil survey maps and making interpretations for rangeland, crop, and forest uses (Reybold and TeSelle 1989). Thus, the plant cover data from STATSGO was inferred rather than actually sampled, and caution should be used in the application of STATSGO range production values to plant community classification or analysis. It should be noted that these data usually are not distributed with STATSGO soil data, because of the generality of the range information (M Hanson, USDA Soil Conservation Service Field Office, Bozeman, Montana; pers comm). Users of STATSGO data who are not familiar with the methods used in compiling the range production data may be unaware of this generality and they may mistakenly use the data to infer vegetation patterns or trends which are unreliable.

The *State Soil Geographic Data Base (STATSGO) Data Users Guide* (USDA 1991) states the data can be used for broad land use planning and evaluating soil resources at the state or regional scale. The notation that must be included on hard copy maps suggests that the data could also be used at the watershed scale (USDA 1991). STATSGO data for Montana are useful at a level of resolution that captures community variability, but plant values should not be used for even gross approximations of general trends in plant cover. Other GIS-based data may be used similarly to infer patterns which are not directly measured. In these cases, the digital data should be validated with field samples to ensure that they accurately reflect real ecological patterns.

We have shown how GIS techniques can be used to relate grasshopper community data to GIS-based environmental variables. Geostatistical methods could also be used to identify spatial patterns in the georeferenced data. The results could then be integrated into decision support software, hazard mapping protocols, and simulation models to predict which species are expected to be abundant given a known set of environmental factors. Additional research on the specific nature of grasshopper-resource associations is necessary before it will be clear which factors should be included in these integrated models.

GI technologies allow the combination of data collected at dramatically different scales and resolutions. While the application of GIS to ecological assessments has given researchers powerful tools for handling data at multiple scales, care should be exercised in choosing both the scale and resolution of the data used, to ensure that data belong to the same domain (Wiens 1989) and the resolution is appropriate to the ecological phenomenon of interest (Allen and Hoekstra 1992).

4 Conclusions

The main findings of this study were (1) grasshopper communities vary across ecoregions in Montana and (2) both Omernik's ecoregions and STATSGO soil attributes are useful in distinguishing among grasshopper and plant communities in Montana. The spatial variability of grasshopper communities within a state has implications for grasshopper management efforts, which may have differing results in plains versus mountain valley rangeland. This study also demonstrates that ecoregions and soil characteristics can be used as indicators of community composition. Because these data are more easily and inexpensively acquired than field data, they might be used as input for grasshopper forecasting or decision-making models to tailor management efforts to the local environment. However, caution should be exercised in applying these conclusions across different sampling years, because plant and grasshopper communities vary temporally as well as spatially. In addition, georeferenced data obtained by digitizing maps or via remote sensing may use potential vegetation or habitat types rather than individual species measurements. These data sets do not have the level of resolution required to investigate the spatial dependency between individual insect and plant species. High-resolution, fine-scale data sets will be needed to clarify these relationships, and GIS technologies will likely prove the best means of manipulating and analyzing those data.

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