PUEBLO CHEMICAL DEPOT GRASSHOPPER MONITORING: 2000 RESULTS

By

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Executive Summary

Conservation biology’s purpose is to study ecological decay and the decrease of biodiversity (Meffe and Carroll 1994, Baldi and Kisbenedek 1997). An important component of accomplishing this task includes identifying and monitoring changes of biota in space and time to prevent degradation and further loss of biodiversity (Baldi and Kisbenedek 1997). This component requires the development of monitoring programs that compare sites exposed to different intensities or types of anthropomorphic disturbances including disturbances associated with livestock grazing. Establishing a scientifically sound monitoring program is a complex undertaking involving multiple tasks including the identification of aims, selection of indicators, selection of managed and control areas and selection of an acceptable sampling scheme (Baldi and Kisbenedek 1997). One of the most important tasks is selecting the appropriate indicators and statistical analyses. An effective indicator species should be (1) sensitive to changes, (2) widely distributed, (3) easily and cost effectively measurable, collectable, and identifiable (stable taxonomy), (4) able to differentiate between natural and anthropogenic variations, and (5) relevant to ecological phenomena (Pearson 1994, Baldi and Kisbenedek 1997). Orthopterans make good indicators because their community structure is sensitive to natural changes in environmental conditions (i.e., plant community variation) and to anthropogenic influences like livestock grazing (Jepson-Innes and Bock 1989, Kemp et al. 1990, Baldi and Kisbenedek 1997, Fischer et al. 1997, Parajulee et al. 1997). In addition, orthopterans are ubiquitous in grassland landscapes and they are easily sampled by sweep-netting and easily identified to species. Finely, orthopterans are key herbivores in grassland biomes and constitute a major portion of the animal biomass (Shure and Phillips 1991). Up to two-thirds of the variation in grasshopper species composition is attributable to human-induced changes in vegetation structure (Fielding and Brusven 1993), thus indicating the strong relationship between human disturbance and grasshopper assemblages. This relationship suggests that grasshoppers are good indicators of grassland naturalness, and natural western North American grassland is rapidly disappearing. For these reasons grasshoppers are used in this research to investigate ecological disturbance on the Pueblo Chemical Depot.

In 1999 the U. S. Fish and Wildlife Service contracted the Colorado Natural Heritage Program (CNHP) to set up a long-term invertebrate monitoring program on Pueblo Chemical Depot (PCD) in Pueblo County, Colorado. The monitoring program was established to detect the influences that vegetation type, grazing disturbance (grazed vs.

ungrazed), and recent changes in grazing protocol have on the structure of invertebrate communities. The three habitat types that were monitored were greasewood scrub, shortgrass prairie and northern sandhill prairie.

To detect differences in species composition 32 invertebrate monitoring plots were established in 2000. Plots were established in greasewood scrub (11), northern sandhill prairie (11) and shortgrass prairie (10). In addition, whether grazing disturbance influence grasshopper composition was investigated on 15 of the plots in areas that experienced past grazing by livestock. Plot location and number will be evaluated in May 2001 with the potential addition of two to four more plots. All plots (the original 32 and any additions) are a randomly selected subset of the 50 vegetation monitoring plots established in 1998 by Renee Rondeau, Ecologist\Botanist, CNHP (Rondeau 1999). In 2000, all 32 invertebrate monitoring plots were sampled twice, once each in August and September. To understand annual variation in species composition and density we will measure the permanent plots on an annual basis from May to September through the year 2003.

The following report presents the methods and results of the 2000 samples.

Sampling Objectives

Our primary sampling goal of monitoring grasshopper community structure at PCD is to detect a 20% change at P=0.1 in grasshopper community structure and density over the three years of the project. We are especially interested in the areas where grazing was terminated in late spring of 1998 (i.e., ammunition workshop area and eastern demolition area).

Methods

Study site and disturbance regime

For information on the study site including general history, location, vegetation, climate and history of livestock grazing see Sovell 2000.

Sampling design and data analysis

The project was designed to sample greasewood scrub, shortgrass prairie and northern sandhill prairie habitat types for differences in grasshopper community structure. In addition, whether grazing disturbance influences grasshopper composition was investigated by placing six of the greasewood scrub plots, four of the shortgrass prairie plots and five of the northern sandhill prairie plots in areas that experienced past grazing by livestock. For an explanation of how plot locations were chosen see Rondeau (1999). This scheme created six sampling groups consisting of two different grazing disturbances (grazed and ungrazed) nested within the three different habitat types mentioned above.

For an explanation of methodology used to sample vegetation see Rondeau (1999). Percent cover of 21 plant species were summarized into seven vegetation types including shrubs (*Chrysothamnus nauseosus, Eriogonum effusum, Zinnia grandiflora*), greasewood (*Sarcobatus vermiculatus*) northern sandhill prairie (*Oligosporus* [*Artemisia*] *filifolius*), cacti (*Opuntia macrorhiza, Opuntia polyacantha, Opuntia phaecantha, Cylindropuntia imbricata*), native perennial grasses (*Aristida divaricata, Aristida purpurea, Chondrosum gracile* [*Bouteloua gracilis*], *Hilaria jamesii, Sporobolus airoides, Sporobolus cryptandrus, Stipa comata*), annual native forbs (*Pectis angustifolia, Zygophllidium hexagonum*) and noxious weeds (*Bassia* [*Kochia scoparia*] *siever, Salsola australis, Ipomoea leptophylla*). These seven vegetation types were compared between habitat types and grazing disturbance with Kruskal-Wallis and Wilcoxon signed ranked tests. To explore possible gradients in vegetation composition, all samples were ordinated using detrended correspondence analysis (DCA; Jongman et al. 1995). DCA is an eigenanalysis ordination technique based on reciprocal averaging that ordinates species and samples simultaneously.

Grasshopper community structure was assessed through intensive sweep net collections at every site; sweep samples provide good estimates of relative abundance and species composition (Evans et al. 1983, Evans 1988). As previously stated grasshopper collections were made in August and September and these collection times were dictated by completion of sample plot installation in late July.

Two transects placed perpendicular to one another and crossing at one end, were used on each plot to estimate grasshopper densities. Each transect consisted of twenty $0.1m^2$ hoops (Onsager 1977, 1991: Onsager and Henry 1977) placed 5m apart, creating a transect 100m in length, with a sampling area of $2m^2$ per transect or $4m^2$ per plot. Density counts were made by approaching each hoop and counting every grasshopper that jumped or flew from within it. Each hoop was then searched for grasshoppers that did not flee. Individual hoops were treated as subsamples; data from all 40 hoops on each plot were pooled and plots were used as replicate samples (11 greasewood, 10 shortgrass and 11 sandhill prairie). Qualitative estimates of species composition were conducted each month by intensively sweeping a five-foot path on each side of both transects on every plot. All collected grasshoppers were frozen for later identification in the laboratory. To minimize bias in estimates of species composition between sites due to interspecific differences in behavior, whenever possible we caught each grasshopper flushed, regardless of ease of capture (Capinera and Sechrist 1982a). The species present were determined by pinning and identifying the samples of adult grasshoppers collected in August and September. Grasshoppers were identified using the keys of Capinera and Sechrist (1982b), and Pfadt (1994). Nymphs were omitted from the analysis because of difficulties in identification.

The frequency distribution of hoop sample counts from within each habitat type by grazing disturbance was expected to approximate a Poisson distribution, and so each observed distribution was tested against a Poisson distribution. For all samples a 95% Poisson confidence interval was calculated and samples whose intervals did not overlap were declared different by inspection (*P* unspecified, but <0.05). Low sample counts in September (N=34) brought into question the reliability of confidence intervals. Onsager (1991) found that as grasshopper sample size increases to 50 individuals, sample confidence intervals decrease considerably. The influence on sample confidence interval is small for sample sizes greater than 50 grasshoppers. Counts for August and September were therefore combined before analysis.

Species richness and evenness were compared between habitat types and grazing disturbance with Kruskal-Wallis and Wilcoxon signed ranked tests. Evenness was calculated using Pielou's (1969) measure [Shannon diversity index÷ln(richness)]. To test for differences in species composition among habitat types and between grazing disturbance types, grasshopper abundance was examined using multi-response permutation procedures (MRPP). MRPP is a nonparametric procedure and thus does not require assumptions associated with alternative parametric tests (multivariate normality and homogeneity of variances; Zimmerman et al. 1985). Euclidian distance and an approximated *P*-value from a Pearson type III distribution of the test statistic was used in the MRPP analysis.

To explore possible gradients in species composition, all samples were ordinated using detrended correspondence analysis. This method has been used successful in the analysis of grasshopper community structure (Kemp et al. 1990, Quinn et al. 1991, Fielding and Brusven 1993, Baldi and Kisbenedek 1997). Coefficients of determination (r^2) are reported using Euclidian distances in ordination space and in original space, allowing for evaluation of how the explained variance was partitioned among the DCA axes (McCune and Mefford 1999). I then compared ordination scores on axis 1 and axis 2 among habitat types and between grazing disturbance types with Kruskal-Wallis and Wilcoxon signed rank tests. This approach allowed use of the DCA scores to reduce the species composition data.

The degree of association of individual grasshopper species to specific habitat types or grazing disturbance regime was measured using indicator-species analysis (Dufrene and Legendre 1997). Indicator values, which were calculated for each species and all six combinations of habitat type and grazing disturbance, combine information on relative abundance and relative frequency of occurrence (Schooley et al. 2000). Perfect indication of a habitat (indicator value=100) occurs when all individuals of a species are in one of the habitats, and each sample from that habitat contains an occurrence of that species. The statistical significance of the maximum indicator value (i.e., highest of the six groups) was tested with Monte Carlo randomization tests (1000 iterations) in which species abundance data were randomized among all 32 study plots.

The DCA, MRPP and indicator-species analysis were conducted using PC-ORD (McCune and Mefford 1999). All other statistical analyses were conducted using SAS (SAS institute 1989).

Results

Vegetation Cover

There were significant differences in vegetation coverage among the habitat types (Kruskal-Wallis χ^2=16.8, df=5, *P*=0.049) (Fig. 1). Grazing disturbance, however, apparently was not responsible for these differences. For all three habitat types, plant coverage of the seven vegetation types varied little between grazed and ungrazed sites. The only significant difference was a higher cover of other shrubs in the grazed shortgrass prairie habitat (Wilcoxon T=31.0, *P*=0.020). Also there is moderate evidence that in grazed greasewood habitats, coverage of noxious weeds was lower (Wilcoxon T=36.0, *P*=0.052).

Differences in vegetative cover seem most influenced by habitat type: greasewood scrub, shortgrass prairie or northern sandhill prairie. Wilcoxon Two-Sample Tests comparing the seven vegetation types among the three pairs of habitats identified many significant differences (Table 1). Shortgrass prairie samples had lower cover of shrubs other than greasewood and sagebrush compared to greasewood (T=60.0, *P*<0.001) and northern sandhill prairie (T=65.5, *P*=0.001) samples. As expected, coverage of northern sandhill prairie was greater in sandhill prairie habitats compared to greasewood (T=66.0, *P*<0.001) and shortgrass prairie (T=55.0, *P*<0.001) habitats. As anticipated, greasewood samples showed greater coverage of greasewood compared to shortgrass prairie (T=55.0, *P*<0.001) and northern sandhill prairie (T=66.0, *P*<0.001) samples. Northern sandhill prairie samples had greater coverage of cacti compared to greasewood (T=90.0, *P*=0.008) and shortgrass prairie (T=71.0, *P*=0.003) samples. Finally, northern sandhill prairie habitats had less cover of both native annual grasses and forbs than did greasewood (grasses: T=172.0, *P*=0.001; forbs: T=88.0, *P*=0.001) and shortgrass prairie (grasses: T=136.0, *P*=0.034; forbs: T=82.5, *P*=0.013) habitats. There was no difference in plant cover of noxious weeds among the habitat types.

By clearly separating the three habitat types (Fig 2), DCA ordination of the seven vegetation types supported the validity of the results of the nonparametric analysis presented above. In addition, vegetation types responsible for structuring the ordination (Pearson $r \geq 0.463$) were identified by Wilcoxon Two Sample Tests as differing significantly among habitats (Fig. 2, Table 1). Also, an effect of grazing disturbance was not evident in the structure of the DCA ordination (Fig. 2), further supporting the results of the nonparametric analysis.

Grasshopper Density

Frequency distributions of the six sampling groups consisting of two different grazing disturbances (grazed and ungrazed) nested within the three different habitat types conformed to the Poisson expectations. Estimates of grasshopper density within all six study groups were extremely low (range 0.45-1.0/m^2) and none were different according to 95% Poisson confidence intervals.

Grasshopper Species Composition

Four hundred eighty-eight grasshoppers were identified to species from collections made during 2000 (Table 2). Thirty-six species of grasshoppers were identified from 24 genera and three families. *Melanoplus* (eight species) was the most species-rich genus and the three most numerous species were *Opeia obscura*, *Ageneotettix deorum* and *Paropomala wyomingensis*. Obligate grass feeders were the most abundant grasshoppers collected, comprising 61% (N=296) of the total sample. The ungrazed samples in all habitats had greater numbers of grasshoppers than did grazed counterparts (Table 3).

Analysis of grasshopper samples identified differences in grasshopper species richness among study plots (Kruskal-Wallis χ^2=11.55, df=5, *P*=0.042), but not in species evenness (Kruskal-Wallis χ^2=3.45, df=5, *P*=0.631). Further examination with Wilcoxon Two-Sample Tests supplied evidence that species richness was greater in shortgrass prairie habitats compared to greasewood (T=162.0, *P*=0.032) and that more grasshopper species occupied ungrazed shortgrass prairie than grazed shortgrass prairie (T=21.0, P=0.040) (Table 4).

MRPP analysis of the six groups of habitat type by grazing disturbance revealed that grasshopper species composition differed among groups (T=-3.1, *P*=0.007, n=6 groups). These differences could result from differences between habitat types, grazing disturbance types or both. I thus tested for differences in grasshopper species composition between each of the three pairs of habitat types and then for grazed and ungrazed samples within each habitat type. This analysis revealed significant differences in grasshopper composition between northern sandhill prairie samples and both greasewood (T=-2.9, *P*=0.017, n=2 groups) and shortgrass prairie (T=-4.2, *P*=0.005, n=2 groups) samples, but not between greasewood and shortgrass prairie samples (T=-1.5, *P*=0.079, n= 2 groups). There were no significant differences between grazed and ungrazed samples on any of the three habitat types (shortgrass prairie: T=-1.6, *P*=0.072; northern sandhill sagebrush: T=0.6, *P*=0.708; greasewood: T=0.9, *P*=0.838; all n=2 groups). This suggests that characteristics of habitat are more important than grazing disturbance in structuring these grasshopper communities. Indicator-species analysis identified 10 species (Table 2) that were associated with either the shortgrass prairie or northern sandhill prairie habitats. Interestingly, this analysis showed that many grasshopper species were strongly associated with ungrazed habitats. Eight of the 10 species identified as having significant indicator values were associated with ungrazed habitats. The ungrazed shortgrass prairie indicators were *Aeoplides turnballi* (indicator value IV=100. *P*=0.012) *Amphitornus coloradus* (IV=62, *P*=0.005), *Cordillacris crenulata* (IV=61, *P*=0.022), *Mestobregma plattei* (IV=42, *P*=0.010), and *Opeia obscura* (IV=42, *P*=0.006); while the ungrazed northern sandhill prairie indicators were *Melanoplus angustipennis* (IV=83, *P*=0.033), *Melanoplus bowditchi* (IV=67, *P*=0.020), and *Paropomala pallida* (IV=52, *P*=0.041). Only two species, *Cordillacris occipitalis* (IV=57, *P*=0.041) and *Tropidolap formosus* (IV=60, *P*=0.005), were associated with grazed habitats, both in northern sandhill prairie. Indicator species analysis did not identify any grasshopper species associated with greasewood habitats. For all 36 grasshopper species, ungrazed and grazed samples within each habitat type were tested for equality of indicator values, revealing a significant association of grasshopper species for ungrazed shortgrass prairie habitats (t=-3.779, df=40, P=0.001). Indicator values were similar between grazed and ungrazed samples in both the greasewood (t=1.761, df=48, P=0.085) and northern sandhill prairie (t=0.417, df=34, P=0.680) habitats.

By clearly separating out northern sandhill prairie samples, DCA ordination of grasshopper abundance for all 36 species validates the nonparametric analysis presented above (Fig. 3). Additionally, three of the five grasshopper species responsible for structuring the ordination (Pearson r$\geq$0.575) were also identified by indicator species analysis as having significant indicator values (Fig. 4). Further analysis of ordination scores indicated that the six groups of grazing disturbance by habitat type separated (Kruskal-Wallis χ^2=18.47, df=5, P=0.002) along axis 1 (eigenvalue=0.539, r^2=0.43, gradient length=3.488) and axis 2 (Kruskal-Wallis χ^2=11.24, df=5, P=0.046; eigenvalue=0.205, r^2=0.08, gradient length=1.696) of the DCA ordination (Fig. 3). This association could result from differences among habitat types, differences between grazing disturbance types or both. I thus tested for concentration of DCA scores on grasshopper abundance between the three pairs of habitat types and then for grazed and ungrazed samples within each habitat type. This analysis showed northern sandhill prairie samples as having significantly greater scores than the other two habitat types on both ordination axes (Table 5). This finding corresponds with ordination results where northern sandhill prairie samples were separate from greasewood and shortgrass prairie samples, which themselves formed a single cluster in the ordination plot (Fig. 3). Analysis of grasshopper abundance revealed significantly greater DCA scores for grazed northern sandhill prairie samples compared to their ungrazed counterparts on axis 2, but no differences between grazed and ungrazed samples within greasewood and shortgrass prairie habitats (Table 5). This corresponds with ordination results where grazed and ungrazed northern sandhill prairie samples were separated along axis 2, whereas grazed and ungrazed samples within greasewood and shortgrass prairie habitats formed a single cluster in the ordination plot (Fig. 3).

Discussion

There were many differences in vegetative cover among the habitat types, whereas differences between grazed and ungrazed samples were minimal. Cover of sagebrush in sandhill prairie and greasewood in greasewood scrub were characteristically greater. In addition, on sandhill prairie habitat cacti were in abundance whereas cover of native grasses and forbs was low. Finally, the percent cover of shrubs other than sagebrush and greasewood was lower on the shortgrass prairie habitats. This all points to strong differences in vegetative structure on the three different habitat types. There were noticeable differences in cover between grazed and ungrazed areas, but these differences were lower in magnitude than those found among the three habitat types. The most noteworthy difference is that percent cover of other shrubs is greater on shortgrass prairie areas that have been grazed. This is particularly interesting when considering that the percent cover of other shrubs is in general lower on shortgrass prairie habitats. That the percent cover of other shrubs is greater on grazed shortgrass prairie areas suggests that grazing may have increased the shrub cover. That this difference influenced grasshopper species composition is supported by the analysis of grasshopper abundance.

Estimates of grasshopper density for all six study groups were extremely low, which may reflect a seasonal decline in abundance associated with onset of the fall and winter period. Although no differences were detected in densities among the six study groups, differences may occur at other times of the year when overall densities are higher (i.e., July). A complete sample from throughout the period of grasshopper activity (May-September) may offer different results.

In analyzing grasshopper species composition it is evident that grasshoppers respond to both patch disturbances created by grazing and to the mosaic created by the patchy distribution of shortgrass prairie, greasewood scrub and northern sandhill prairie throughout the landscape. Species richness is greater on ungrazed shortgrass prairie habitats (see Table 4). In addition, of the 10 species identified with significant indicator values (IV), eight were associated with ungrazed sampling areas, and five of these were associated with ungrazed shortgrass prairie. Also, the only significant differences attributable to grazing were for greater indicator value scores on ungrazed shortgrass areas compared to grazed shortgrass areas. Shortgrass prairie areas had greater numbers of obligate grass-feeding species than did grazed counterparts, and obligate forb feeders were noticeably fewer on grazed shortgrass areas (see Table 3). This suggests that grasshoppers reacted to grazing of shortgrass prairie landscapes with changes in species composition. There is mild evidence that grazing disturbance also influences grasshopper community composition on northern sandhill prairie habitats. DCA scores on axis 2 were greater on the grazed sandhill prairie areas compared to ungrazed counterparts, but axis 2 explained only a small amount of variation (5%). Five of the 10 identified indicator species, however, were associated with sandhill prairie habitats (three ungrazed, two grazed). On ungrazed sandhill prairie areas the abundance of obligate grass-feeding grasshopper species was much greater compared to grazed areas (see Table 3). This may suggest that grazing disturbance also plays a role in structuring grasshopper communities in northern sandhill prairie landscapes. Analysis of percent vegetation cover, however, revealed no differences in plant community structure between grazed and ungrazed sandhill prairie areas. This suggests that some other characteristic of plant community structure not measured by this research has been influenced by grazing disturbance and is in turn affecting grasshopper communities in sagebrush habitats. It is worth noting, however, that MRPP analyses did not reveal any differences between grazed and ungrazed samples in any of the three habitat types.

MRPP analysis did, however, find significant differences in grasshopper species composition between sandhill prairie areas and the other two habitat types, possibly because grasshopper abundance was far greater in sandhill prairie habitats than in the other two habitat types (see Table 3). This, coupled with the much greater DCA scores for sandhill prairie samples (see Table 5) on both axis 1, which explains 43 % of the variation, and on axis 2, suggests that plant community structure at the large habitat scales I examined may exert a greater influence on grasshopper community composition than does grazing disturbance.

These analyses are based upon preliminary samples collected only during the months of August and September in 2000. Analysis of a complete collection of samples taken from May through September as planned for summer 2001 may produce different results. A more complete picture of community structure afforded by one complete summer collection will help determine when collections will be most useful in describing grasshopper density and community composition. It may not be necessary to make collections throughout the summer, but only during periods with highest grasshopper density and during periods when species composition varies the greatest between study groups.

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Table 1. Correlation of habitat type on plant cover of seven vegetation types. Wilcoxon Two-Sample Tests were used to compare vegetation cover for all possible pairs of habitat types (greasewood-shortgrass prairie, greasewood-northern sandhill prairie and shortgrass prairie-northern sandhill prairie). Indicated differences for a specific habitat type are in comparison to the other two habitat types.

	Habitat Type – Significant Differences[1]		
Vegetation Type	Greasewood	Shortgrass Prairie	Northern Sandhill Prairie
Other shrub		less**	
Northern sandhill Prairie			greater**
Greasewood	greater***		
Cacti	greater**(than shortgrass)		greatest*
Native annual grasses		less*	
Native annual forbs		less*	
Noxious weeds[2]			

1 * $P \leq 0.05$; ** $P \leq 0.001$; *** $P \leq 0.0001$

2 There are no significant differences in plant cover of noxious weeds for any pair of habitat types

Table 2. List of orthopteran species and their abundances given as number of individuals/habitat. The number of plots surveyed for each grazing protocol, vegetation type and month are given in parentheses.

		SITES												
		SGUG		SGG		SSUG		SSG		GWUG		GWG		Species Totals
ORTHOPTERIDEA SPECIES	FEEDING CATEGORY	Aug. (6)	Sept. (6)	Aug. (5)	Sept. (4)	Aug. (6)	Sept. (5)	Aug. (5)	Sept. (5)	Aug. (5)	Sept. (3)	Aug. (7)	Sept. (5)	
Gomphocerinae (Slantfaced)														
Ageneotettix deorum	OG	10	4	1	1	11	10	3	5	8	5	4	3	65
**Amphitornus coloradus*	OG	4				2	13			1	1			21
Aulocara elliotti	OG						2							2
Aulocara femoratum	OG	2					7	1						10
Boopedon nubilum	OG		1											1
**Cordillacris crenulata*	OG	2				4	15				3			24
**Cordillacris occipitalis*	OG	2					1			3				6
Mermiria bivittata	OG	1	2				3			1	1			8
**Opeia obscura*	OG	16	10	10	3	8	31	6	18	3	8	2		115
**Paropomala pallida*	?	2								5	8	2	3	20
Paropomala virgata	?	1					1			3				5
Paropomala wyomingensis	OG	4	1			6	4	4	1	6	9	1		36
Phlibostroma quadrimaculatum	OG					2	4							6
Oedipodinae (Bandwinged)														
Arphia pseudonietana	MF		1	7	4			2	6					20
Hadrotettix trifasciatus	MF	2				3	5	3	1					14
Hippiscus ocelote	MF	1												1
Hippopedon capito	?	4		1			1	2						8
**Mestobregma plattei*	?	6	1	1		5	12	2	2	1	1	1		32
Metator pardalinus	OG						1							1
Spharagemon collare	MF			1						2	1	1	2	7
Spharagemon equale	MF			3		1			1					5
Trachyrhachys aspera	OG							1						1
Trimerotropis pallidipennis	MF			1		1					1			3
**Tropidolap formosus*	OF							3	2					5
Melanoplinae (Spurthroated)														
**Aeoloplides turnbulli*	OF						3							3
Dactylotum bicolor	OF		1				1							2
Hesperotettix speciosus	OF	1									1			2
Hesperotettix viridis	OF	3	1				1							5
**Melanoplus angustipennis*	MF									1	4		2	7
Melanoplus arizonae	?								2			1	1	4
**Melanoplus bowditchi*	OF	1		1				1		3	6		7	19
Melanoplus gladstoni	MF		1											1
Melanoplus lakinus	MF								1					1
Melanoplus occidentalis	MF					1	2							3
Melanoplus packardii	MF	3					3			2	8	4	3	23
Melanoplus sanguinipes	MF			1			1							2
Total No. of Grasshoppers Collected														488

SGUG: shortgrass ungrazed; SGG: shortgrass grazed; SSUG: northern sandhill prairie ungrazed; SSG: northern sandhill prairie grazed; GWUG; greasewood ungrazed; GWG: greasewood grazed; OF: obligate forb; OG: obligate grass; MF: mixed feeder.

* Species with significant indicator values ($P \leq 0.05$).

Table 3. Summary of grasshopper abundance by feeding and habitat classification, and grazing disturbance.

	Feeding Type				
Habitat Classification*	Obligate Grass	Obligate Forb	Mixed Feeder	Unknown	Totals
SGUG	59	7	8	14	88
SGG	15	1	17	2	35
SSUG	124	5	17	19	165
SSG	39	6	14	8	67
GWUG	49	10	19	18	96
GWG	10	7	12	8	37
Totals	296	36	87	69	488

* Habitat classifications are as defined in Table 1.

Table 4. Influence of habitat type and grazing disturbance on species richness and evenness. Wilcoxon Two-Sample Tests were used to compare grasshopper species richness between grazing disturbances within habitat types and for all possible pairs of habitat types (greasewood-shortgrass prairie, greasewood-northern sandhill prairie and shortgrass prairie-northern sandhill prairie). Numbers of plots sampled for each habitat type/grazing disturbance are shown in parentheses. Significant *P*-values are given in bold type.

	Community Composition Measure			
Grazing Disturbance Comparison	Mean Richness	*P*-value	Mean Evenness	*P*-value
Greasewood				
ungrazed (5)	3.4	0.096	1.0	0.165
grazed (7)	6.1		1.3	
Shortgrass prairie				
ungrazed (6)	10.8	**0.0397**	1.2	0.137
grazed (5)	5.8		1.1	
Northern sandhill prairie				
ungrazed (6)	5.8	0.099	1.1	0.641
grazed (5)	7.4		1.1	
Habitat Comparison				
Greasewood-Shortgrass	5.0		1.2	
	8.5	**0.032**	1.2	0.463
Greasewood-northern sandhill prairie	5.0		1.2	
	6.5	0.055	1.1	0.356
Shortgrass-northern sandhill prairie	8.5		1.2	
	6.5	0.088	1.1	0.359

Table 5. Influence of habitat type and grazing disturbance on grasshopper species abundance. Wilcoxon Two-Sample Tests were used to compare DCA scores between grazing disturbances within habitat types and for all possible pairs of habitat types (greasewood-shortgrass prairie, greasewood-northern sandhill prairie and shortgrass prairie-northern sandhill prairie). Numbers of plots sampled for each habitat type/grazing disturbance are shown in parentheses. Significant *P*-values are given in bold type.

	Axis 1		Axis 2	
Grazing Disturbance Comparison	Mean	P-Value	Mean	P-Value
Greasewood				
Ungrazed (5)	99	0.117	85	0.100
Grazed (7)	164		108	
Shortgrass prairie				
Ungrazed (6)	128	0.197	115	0.261
Grazed (5)	147		78	
Northern sandhill prairie				
Ungrazed (6)	309	0.292	114	**0.014**
Grazed (5)	307		167	
	307			
Habitat Comparison				
greasewood-shortgrass	135		98	
	135	0.180	100	0.336
greasewood-northern sandhill prairie	135		98	
	308	**<0.001**	138	**0.016**
shortgrass-northern sandhill praire	135		100	
	308	**<0.001**	138	**0.017**

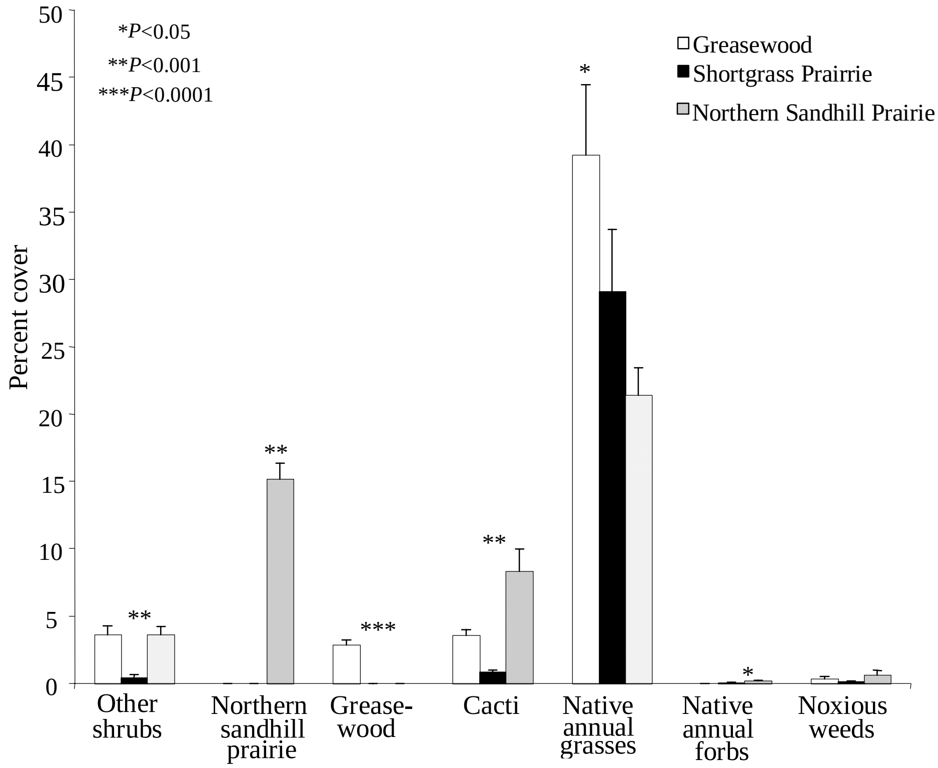

Figure 1 Correlation of habitat type on plant cover of seven vegetation types. Each bar represents one mean (+1 SE). Sample sizes: greasewood N=11, shortgrass prairie N=10 and northern sandhill prairie N=11.

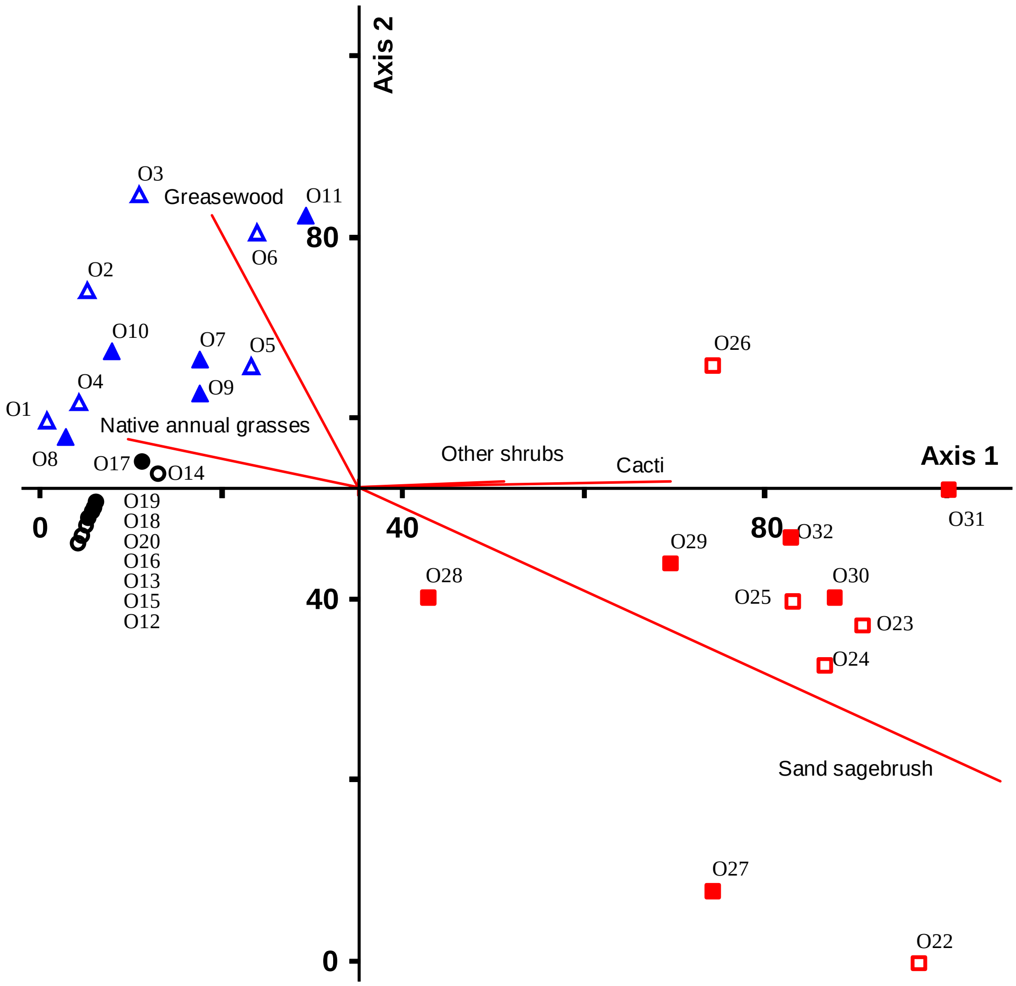

Figure 2 Detrended correspondence analysis ordination joint plot of 32 study plots based on the percent cover of 7 vegetation types and percent canopy cover for those vegetation types most responsible for structuring the ordination. Lines indicate directions that corresponding plant species abundances increases most, and line length is proportional to the rate of that change. Disturbance categories are indicated by symbols: ▲ greasewood ungrazed N=5; △ greasewood grazed N=6; ● shortgrass ungrazed N=5; ○ shortgrass grazed N=4; ■ northern sandhill prairie ungrazed N=6; □ northern sandhill prairie grazed N=5. Site codes: greasewood grazed (O1-O6); greasewood ungrazed (O7-O11); shortgrass grazed (O12-O15); shortgrass ungrazed (O16-O21); northern sandhill prairie grazed (O22-O26); northern sandhill prairie ungrazed (O27-O32).

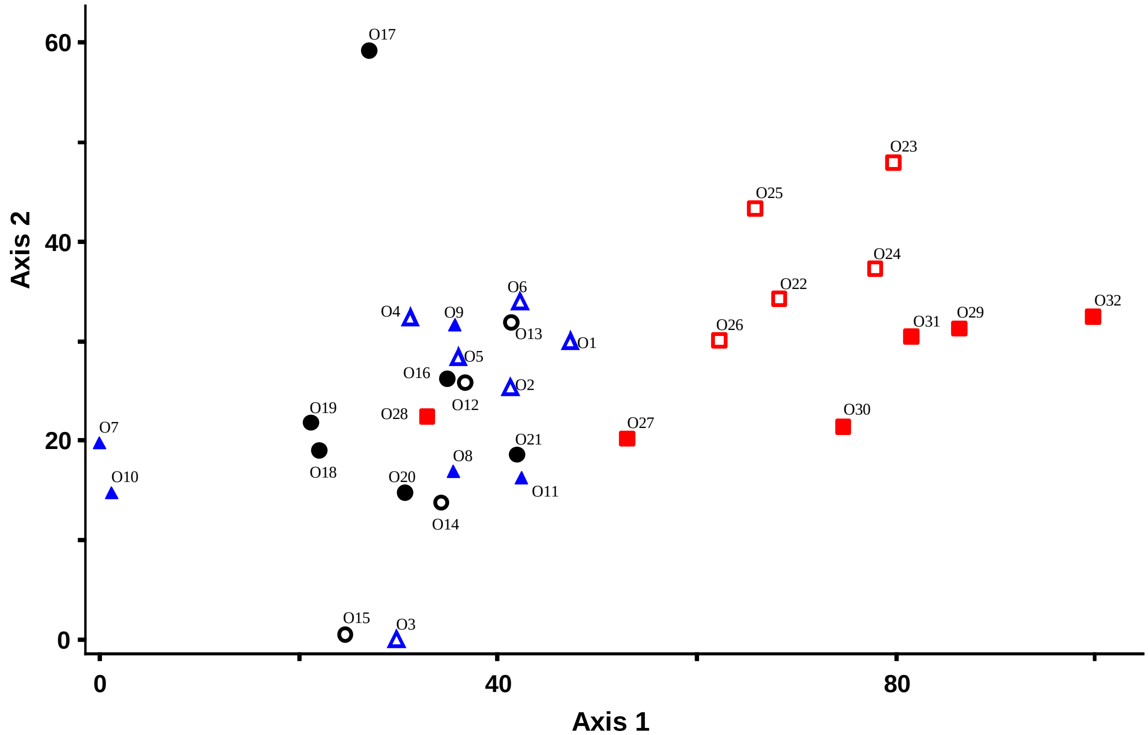

Figure 3 Detrended correspondence analysis ordination of 32 study plots based on the abundance of 36 grasshopper species collected in 2000. Site symbols and codes are the same as in Figure 2.

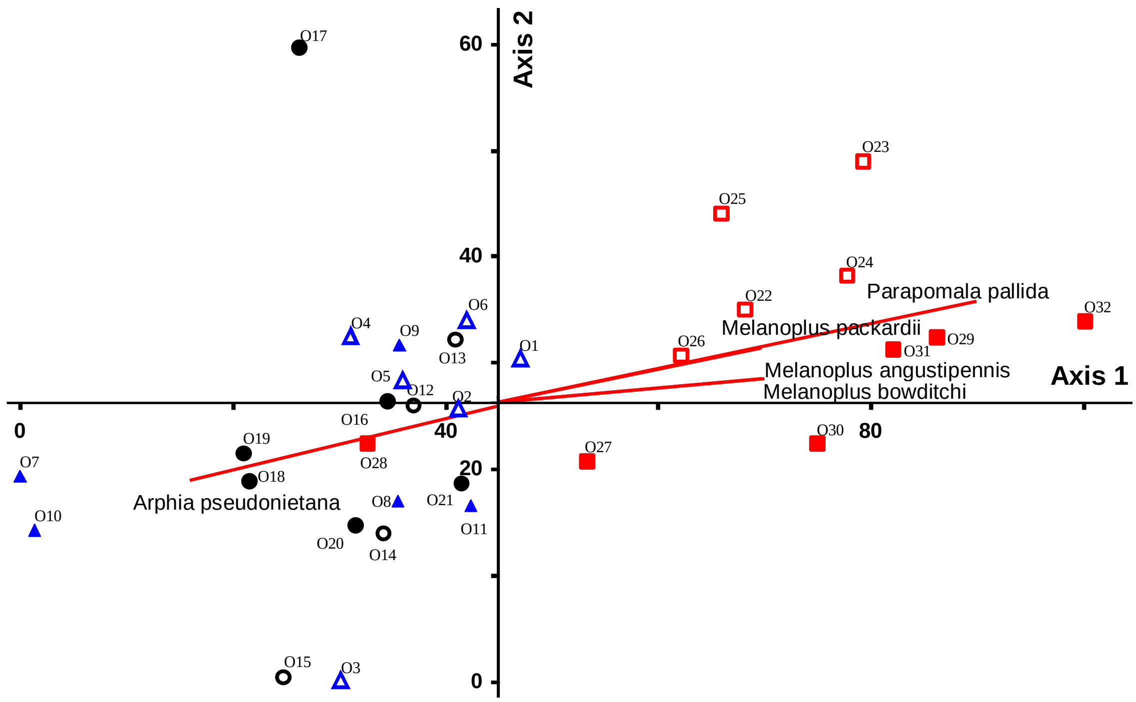

Figure 4 Detrended correspondence analysis joint plot of 32 study plots and the grasshopper species with greatest influence on ordination structure. Lines indicate directions that corresponding grasshopper species abundance increases most, and line length is proportional to the rate of that change. Site symbols and codes are the same as in Figure 2.