2008-07-16

Arthropod and Plant Communities as Indicators of Land Rehabilitation Effectiveness in a Semi-arid Shrub-steppe

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Arthropod and plant communities as indicators of land rehabilitation effectiveness in a semi-arid shrub-steppe

by

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A thesis submitted to the faculty of

Brigham Young University

in partial fulfillment of the requirements for the degree of

Master of Science

Department of Plant and Wildlife Sciences

Brigham Young University

August 2008

BRIGHAM YOUNG UNIVERSITY

GRADUATE COMMITTEE APPROVAL

of a thesis submitted by

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This thesis has been read by each member of the following graduate committee and by majority vote has been found to be satisfactory.

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BRIGHAM YOUNG UNIVERSITY

As chair of the candidate's graduate committee, I have read the thesis of Eric Gardner in its final form and have found that (1) its format, citations, and bibliographical style are consistent and acceptable and fulfill university and department style requirements; (2) its illustrative materials including figures, tables, and charts are in place; and (3) the final manuscript is satisfactory to the graduate committee and is ready for submission to the university library.

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ABSTRACT

Arthropod and plant communities as indicators of land rehabilitation effectiveness in a semi-arid shrub-steppe

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Master of Science

We describe a case study evaluating the ecological impact of *Bromus tectorum* L. (cheatgrass) invasion following fire disturbance and the effectiveness of revegetation in improving ecological integrity in a degraded semi-arid shrub steppe system. The effectiveness of rehabilitation efforts was assessed from measurements of arthropod richness, vegetation and arthropod community composition, and ground cover characteristics in three habitats: undisturbed, burned and weed-infested (*B. tectorum*), and burned and rehabilitated with native and non-native vegetation. Arthropods were collected in each habitat using pitfall traps. Differences in arthropod richness were compared using rarefaction curves. Non-metric multidimensional scaling, and non-parametric multivariate statistical procedures including analysis of similarity and similarity percentages routines were used to compare arthropod and vegetation community composition and ground cover characteristics between habitats. Arthropod communities in the rehabilitated habitat were distinct from and intermediate to those observed in the undisturbed and weed-infested habitats. Rehabilitation in this instance resulted in an improvement in ecological integrity and perhaps an intermediate step on the way complete restoration. Arthropod richness, arthropod and vegetation community composition, and ground cover characteristics were all useful indicators of ecological integrity, but returned slightly different results. Assessing multiple variables yielded the most complete understanding of the habitats studied.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Introduction

Ecological integrity has been defined as "system wholeness, including the presence of appropriate species, populations, and communities and the occurrence of ecological processes at appropriate rates and scales (Angermeier & Karr, 1994; Karr, 1991) as well as the environmental conditions that support these taxa and processes (Dale & Beyler 2001)." Disturbance, including weed invasion, can damage ecological integrity (Ogle et al. 2003). The invasion of *Bromus tectorum* L. (cheatgrass), an exotic annual grass species, has contributed to rangeland degradation in sage-steppe biomes. The invasion of *B. tectorum* has led to a shift in the fire regime of affected areas: sagebrush communities that historically burned every 60 – 110 years may experience fire every 5 years following the invasion of *B. tectorum* (Roberts 1990, Whisenant 1990). This shorter fire cycle prevents or retards recruitment of native plants; *B. tectorum* has also been observed to compete with native plants for water or other resources, thereby reducing native plant production (Melgoza et al. 1990, Ogle et al. 2003). Thus *B. tectorum* invasion can effect a shift from a native plant community to a *B. tectorum* dominated community approaching or reaching a monoculture (Whisenant 1990). This shift in vegetation can lead to reduced faunal as well as floral diversity (Roberts 1990) and has threatened important habitat, including big-game winter range (Updike et al. 1990). Additionally, the annual root system of *B. tectorum* offers poor resistance to erosion, making areas inundated with *B. tectorum* more susceptible to severe erosion. (Knapp 1996).

The objectives of rangeland rehabilitation (especially fire rehabilitation) efforts implemented in response to rangeland degradation include protecting life and property and minimizing unacceptable degradation to natural and cultural resources (US Department of Agriculture Forest Service 2004) by reducing erosion and limiting the invasion of undesirable annual species (Pellant 1990, Beyers 2004). Such efforts have historically involved planting non-native perennial species (Harris & Dobrowolski 1986, Roundy 1997, Beyers 2004). The use of non-native species in land rehabilitation alters the successional trajectories of seeded areas (Bakker & Wilson 2004) and introduces a new type of disturbed community. Non-native plant species may compete with native plants and could thereby preclude recovery of native vegetation communities (Beyer 2004). Recently, the use of native plants and seeds from locally collected sources has been advocated (US Department of Agriculture Forest Service 2004), demonstrating increased interest in restoring native plant communities. Even when native species are used in rehabilitation efforts, resulting vegetation communities may still differ from undisturbed communities due to the use of "native-but-not-resident" species (Parmenter & MacMahon 1990). Rehabilitation represents an additional disturbance to rangelands that may or may not contribute to restoration of ecological integrity, or produce a shift in successional trajectories toward a natural condition (Parmenter & MacMahon 1990).

Though many rehabilitation and restoration projects have been implemented, relatively few have been evaluated relative to their success in restoring ecosystem integrity (Ruiz-Jaen & Aide, 2005a). When restoration success has been assessed, the evaluations have most commonly been based on attributes of vegetation such as diversity and structure (Ruiz-Jaen & Aide 2005a, Herrick et al. 2006). Many have suggested that restoration success should be monitored with respect to the entire ecosystem, not just vegetation (Block et al. 2001, Longcore 2003, Ruiz-Jaen & Aide, 2005b).

Arthropods can be a valuable indicator group for measuring restoration success and ecological integrity (Kremen et al. 1993, Burger et al. 2003, Karr & Kimberling 2003). Despite the challenges of limited baseline data, limited identification expertise and limited knowledge of the natural histories of many arthropods (McIntyre et al. 2001, Longcore 2003), several characteristics contribute to their utility as indicators of ecological integrity. The small size and short generation time of arthropods make them sensitive to even subtle changes in habitat quality; arthropods also occupy a wide range of habitats and perform diverse ecological roles (Kremen 1993, Longcore 2003). Because of these characteristics arthropods can indicate ecosystem functionality to some degree. Some studies investigate a single arthropod taxon, but others suggest that examining multiple taxa can yield a better understanding of complex ecosystems (Carignan & Villard 2002, Karr & Kimberling 2003).

We describe a case study evaluating the ecological impact of *B. tectorum* invasion following fire disturbance and the effectiveness of revegetation in improving ecological integrity in a degraded semi-arid shrub steppe system. The effectiveness of rehabilitation efforts was assessed from measurements of arthropod richness, vegetation and arthropod community composition, and ground cover characteristics in three habitats: undisturbed, burned and weed-infested (*B. tectorum*), and burned and rehabilitated with native and non-native vegetation. Our objectives were to provide insight into the ecological changes that can occur as a result of *B. tectorum* infestation and land rehabilitation following fire disturbance, and to determine the suitability of the indicators used here as ecological monitors in this system.

Study Site

The study site was located near the southern end of the Cedar Mountains in western Utah on Dugway Proving Grounds, approximately 100 km southwest of Salt Lake City at 40°15′13.74″ N latitude, 112°49′09.01″ W longitude. Historically, vegetation in the area was that typical of a sagebrush-steppe biome. The study area receives 8 to 12 inches of precipitation annually, has a frost free period varying from 100 to 140 days, and consists of soil characterized in the Hiko Peak – Checkett complex. Soil in the Hiko Peak – Checkett complex has a moderate potential for seedling survival, moderate potential for damage by fire (damage to nutrient, physical and biotic soil characteristics), and a slight erosion hazard (Soil Survey Staff 2007).

In 1994 a fire burned through a portion of the study area removing much of the sagebrush (*Artemisia tridentata* Nutt.) from the affected region. Part of the burned area was subsequently rehabilitated by drill-seeding native and non-native shrubs and grasses. The remainder of the burned area was not treated and is now dominated by *Bromus tectorum* L. an exotic weed associated with rangeland degradation (Ogle et al. 2003). Thus the site contains three adjacent areas representing three habitats: undisturbed, weed-infested, and rehabilitated.

The undisturbed habitat provided a useful reference to compare with the weed-infested and rehabilitated habitats. Though the undisturbed habitat could not be characterized as pristine due to the presence of *B. tectorum* and other weedy species, it included an intact shrub component representative of conditions in the absence of fire. The undisturbed habitat exhibited an ecological condition that the system apparently could support and thus could be used to define a theoretically plausible goal for restoration efforts in adjacent areas, and a valuable model community (Parmenter & MacMahon 1990).

Materials and Methods

Arthropod Sampling

Pitfall traps were used to sample terrestrial arthropods from each of three habitats representing undisturbed, weed-infested, and rehabilitated conditions. Traps consisted of two plastic 0.5L (16 ounce) cylindrical containers with a diameter of 10 cm. Containers were nested together and buried such that the lip of the upper container was even with the soil surface. The traps were installed in arrays of nine traps arranged in three rows of three traps. Each trap was 10 m from its nearest neighbor (see Pik et al. 1999 and Schnell et al. 2003). Three arrays of 9 traps were placed in each of the three habitats sampled, yielding a total of 27 traps in each habitat, 81 traps in all habitats combined. Trapping periods consisted of 24 hours during which time all traps were active. Active traps were filled 1/3 full with soapy water to break the surface tension and thereby reduce the probability of escape of captured arthropods. A 20 cm square piece of plywood supported 2 cm above the surface of the soil on wooden blocks was placed over the traps to reduce evaporation of the water used in the trap, to reduce the occurrence of non-target organisms, and to reduce contamination of the trap by rain or wind-blown debris. Traps were active for 11 trapping periods during the summer of 2003 (12 June, 19 June, 10

July, 17 July, 24 July, 31 July, 7 August, 14 August, 21 August, 28 August and 4 September), and 8 trapping periods during the summer of 2004 (26 May, 9 June, 22 June, 7 July, 20 July, 4 August, 18 August, and 31 August). After each 24 hour trapping period, arthropods were collected from each trap and preserved in 70% ethyl alcohol.

Of the arthropods that occurred in the traps, those that are primarily limited to ground-dwelling habits were selected for analysis (McIntyre et al. 2001, Ausden & Drake 2006). Though highly mobile insects such as flies and wasps did occur in the traps, these were not included in this analysis because the sampling procedures were designed to target ground dwelling arthropods, and capture rates of other insects may not accurately represent localized populations. Further justification for restricting the analysis to arthropods with fairly limited mobility stems from the relatively close proximity of the habitats being compared. Insects that regularly fly significant distances may have come from sources beyond the boundaries of each habitat. This study focused on arthropods more closely tied to specific and localized environmental conditions.

The insects chosen for analysis were identified to the family level following Triplehorn and Johnson (2005). Non-insect arthropods were identified to order. Individuals in the families Tenebrionidae (Coleoptera), and Tettigoniidae (Orthoptera) were identified to species. The total number of arthropods in each of the taxa described above was determined for each trap in each trapping period. Abundance data were summed within trap arrays and averaged across trapping events within years to yield 6 samples from each habitat that were used to describe terrestrial arthropod community composition (see Community Composition Analysis below).

Taxonomic richness was compared between habitats within years and between years within habitats. Because the number of individuals sampled varied between habitats and between years, comparisons of taxon richness were computed using individual based rarefaction curves (see Gotelli & Colwell 2001). These curves were created using the Species Diversity procedure in EcoSim700 with 1000 iterations and independent sampling (Gotelli & Entsminger 2001). Data used to create the curves consisted of taxon abundance data combined across traps and arrays.

Vegetation and Ground Cover Sampling

Vegetation data were collected from each pitfall trap array location. This was accomplished along four 20m transects arranged in the cardinal directions from the center pitfall trap. Ground cover and aerial cover data were assessed using 0.25 m^2 8-point quadrats placed at regular intervals (4m) along each transect.

Percent ground cover occupied by bare ground, plant litter, plant crown, and cryptogamic crust was estimated by recording the cover type directly below each of the 8 points on the frame at each sampling location. Average percent ground cover for each category in each array location and total within each habitat was computed by dividing the total number of occurrences of each ground cover category by the total possible occurrences. These data were analyzed simultaneously using the same multivariate techniques for analysis of community composition described below.

Ocular estimates of aerial cover class were given for each species contributing to canopy cover in each quadrat. Cover classes were 1 (0-1% cover), 2 (1-5% cover), 3 (5-15% cover), 4 (15-25% cover), 5 (25-50% cover), 6 (50-75% cover), 7 (75-95% cover), and 8 (95-100% cover). Cover class midpoints were used to calculate average aerial cover (and standard errors) by species for each array location and for all array locations within each habitat combined. Aerial cover data from each trap array location were used to characterize vegetation community composition.

Community Composition Analysis

Arthropod and vegetation community compositions were characterized (separately) from the data described above using the statistical package Primer v6 (Clark & Gorley 2006). To reduce the influence of highly abundant taxa, all data were square-root transformed (Clark & Warwick 2001). A resemblance matrix was created by calculating Bray-Curtis similarities for each pairwise comparison of trap array data. Non-metric multidimensional scaling (NMDS) plots were used to graphically represent the data in the resulting resemblance matrices. Differences in community composition were tested for significance using an analysis of similarities procedure (ANOSIM in Primer v6). A 2-way crossed ANOSIM procedure was used to test for significance in differences in arthropod community composition in habitat groups and year groups simultaneously. Because vegetation and ground cover data were collected only once, a 1-way ANOSIM was performed to test for significance of differences in vegetation community composition between habitats.

To determine the percent contribution of each variable being analyzed to within group similarity and to between group dissimilarity, a similarities percentages procedure (SIMPER) in Primer v6 was used (Clark & Gorley 2006). The percent contribution of each arthropod taxon to similarity within habitats and years and to dissimilarity between habitat-types and between years was determined using a 2-way SIMPER procedure based on the Bray-Curtis index of similarity. The percent contribution of each plant species to within habitat similarity and between habitat dissimilarity was assessed using a 1-way SIMPER procedure. A 1-way SIMPER procedure was also used to assess the percent contribution of each ground cover variable to within habitat similarity and between habitat dissimilarity. The RELATE function in Primer v6 (Clark and Gorley 2006) using the Spearman rank correlation method and 999 permutations was used to test for any relationship between the arthropod and vegetation communities.

Results

Arthropod Richness

A total of 5,275 terrestrial arthropods representing 25 taxa (Table 1) were caught during the two years of sampling (3,174 in 2003 and 2,101 in 2004). The greatest abundance of all taxa combined (1,593) was observed in the weed-infested habitat in 2003. In that year, 866 terrestrial arthropods were caught in the undisturbed habitat and 715 in the rehabilitated habitat. In 2004 the greatest abundance of terrestrial arthropods (746) occurred in the undisturbed site, followed by the rehabilitated (712) and the weed-infested (643) habitats.

Significant differences in terrestrial arthropod richness were observed between habitats in both 2003 and 2004 as evidenced by the individual based rarefaction curves (Figure 1). In both years, observed richness was significantly greater (no overlap in 95% confidence intervals) in the weed-infested habitat than either the rehabilitated or the undisturbed habitat. No significant differences in richness were observed between the undisturbed and rehabilitated habitats either year (95% confidence intervals overlapped both years). Taxa that occurred in the weed-infested habitat, but not in either of the other two habitats included *Coniontis* sp., *Edrotes ventricosa*, and *Eusattus muricatus* (Coleoptera: Tenebrionidae), Staphylinidae (Coleoptera), and Stenopelmatidae (Orthoptera).

Significant differences in taxon richness were observed between years within habitats (Figure 2). There was no overlap in the 95% confidence intervals of the individual based rarefaction curves comparing differences between years within either the weed-infested or the rehabilitated habitats, indicating a significant reduction in terrestrial arthropod taxon richness in these habitats from 2003 to 2004. No significant difference in taxon richness was observed in the undisturbed habitat between years.

Arthropod Community Composition

The NMDS (Figure 3) plot of arthropod data had a stress value of 0.09. This was small enough to indicate that this representation was a good depiction of the relationships between the data points (Clarke and Warwick 2001). The NMDS plot showed that points representing trap arrays from any given habitat were plotted close together, indicating within habitat similarity. That there was no overlap of points representing different habitats demonstrates dissimilarity between habitats. The points representing data from the rehabilitated habitat were plotted between those representing data from the undisturbed and weed-infested habitat types indicating that the terrestrial arthropod community observed in the rehabilitated habitat was intermediate to the communities observed in the undisturbed and weed-infested habitats. The NMDS plot also demonstrated the changes in community composition that occurred between years. While it is apparent that differences were observed between years, no consistent pattern was evident across all habitats.

The analysis of similarities procedure showed significant differences in community composition between habitats (R=0.848) at the p=0.001 level and between years at the p=0.002 level (R=0.494). Pairwise comparisons of habitats indicated differences between the weed-infested and rehabilitated habitats significant at the p=0.01 level (R=0.815), between the weed-infested and undisturbed at the p=0.01 level (R=1), and between the rehabilitated and undisturbed habitats at the p=0.01 level (R=0.944). Thus the greatest differences in community similarity were observed between the weed-infested and the undisturbed habitats, and the difference between the rehabilitated and undisturbed habitats was less extreme than the difference between the rehabilitated and weed-infested habitats, as evidenced by the R-values cited above.

SIMPER was used to quantify the contribution of each taxon to dissimilarity of arthropod communities between habitats (Table 2) and between years (Table 3).

Vegetation Community Composition

Sixteen plant species were observed in the vegetation sampling procedures (Table 4). The greatest richness (13 species) was seen in the rehabilitated habitat, followed by the undisturbed (9 species) and weed-infested (4 species) habitats. Higher richness in the rehabilitated habitat was due mostly to the presence of species seeded as part of the rehabilitation process. Average aerial cover of all plant species combined was greatest in the weed-infested habitat (55%), followed by the undisturbed and rehabilitated habitats (26% and 17% respectively).

The NMDS plot of the vegetation community composition data (Figure 4) showed that samples from each habitat were plotted closer to each other than to samples from other habitats. Superimposed similarity levels demonstrated the degree of similarity within habitats.

The ANOSIM test showed that differences in vegetation community composition between habitats were significant at the p=0.05 level. The global R-statistic in this case was 1, the highest possible value, indicating greater similarity within all habitats than between any samples from different habitats. Pairwise tests for significance also returned R-statistics of 1 (significant at the p=0.1 level) for each between-group comparison.

Contributions of each species to between habitat dissimilarity are displayed in Table 5.

Ground Cover

Ground cover data are presented in Table 6. The NMDS plot (Figure 5) of the ground cover data showed two distinct groups, one consisting of data points from the weed-infested habitat, and another group consisting of data points from both the undisturbed and rehabilitated habitats. Results of the ANOSIM test confirmed the pattern demonstrated by the NMDS plot. The global R-statistic (0.564) indicated that significant differences existed between habitats at the p=0.05 level. Pairwise comparisons of the habitats demonstrated that the differences were between the weed-infested and rehabilitated habitats (R=1, significant at the p=0.1 level), and between the weed-infested and undisturbed habitats (R=1, significant at the p=0.1 level). The pairwise comparison of the rehabilitated and undisturbed habitats showed no significant difference between these data points. The R-statistic in this case was negative (R= -0.259) indicating greater variation within than between these habitats.

Contributions of each ground cover variable to between habitat dissimilarity are presented in Table 7.

Results of the RELATE procedure indicated a relationship between the terrestrial arthropod data and the vegetation data at the p=0.04 significance level. The relationship between the arthropod data and the ground cover data was significant at the p=0.05 level. When ground cover data were included with vegetation data, the relationship between the resulting resemblance matrix and the terrestrial arthropod data was significant at the p=0.03 level.

Discussion

Arthropod Richness

As in other studies, we found that fire disturbance can significantly impact arthropod diversity (Moretti et al. 2006) Even an increase in richness as observed in the weed-infested habitat in this case is a departure from an undisturbed condition and thus represents a reduction in ecological integrity under the definition that ecological integrity "includes the presence of appropriate species, populations, and communities and the occurrence of ecological processes at appropriate rates and scales (Karr 1991, Angermeier & Karr 1994) as well as the environmental conditions that support these taxa and processes (Dale & Beyler 2001)." That the rehabilitated community exhibited the same taxon richness as observed in the undisturbed community suggests that rehabilitation in this case facilitated a shift in arthropod richness towards an undisturbed condition, and was thus at least in part successful in improving ecological integrity. This finding is in contrast to other studies that observed lower arthropod richness in rehabilitated or reclaimed areas than in undisturbed habitats (Lomov et al. 2006, Longcore 2003, Parmenter & MacMahon 1990), but similar richness and diversity of some arthropods in undisturbed and reclaimed sites has also been observed (Nichols & Nichols 2003).

The significant reduction in terrestrial arthropod richness in both the weed-infested and rehabilitated habitats from 2003 to 2004 suggest that richness in these habitats may be less stable than observed in the undisturbed habitat, where no change in terrestrial arthropod richness was observed between years.

Arthropod richness data suggest that in this instance, rehabilitation efforts produced a system capable of supporting a terrestrial arthropod community with similar richness to that observed in an undisturbed habitat, though arthropod richness in the rehabilitated habitat may be less stable. Thus, the rehabilitation efforts in this case appear to have contributed to an improvement in ecosystem integrity.

Arthropod Community Composition

Fire disturbance and subsequent weed invasion significantly altered the terrestrial arthropod community. Rehabilitation efforts also appear to have had a significant effect on the terrestrial arthropod community in this area. The NMDS plot of arthropod community data (Figure 3) indicates that the terrestrial arthropod community in the rehabilitated habitat displays characteristics intermediate to the communities represented in the weed-infested and undisturbed habitats, suggesting that rehabilitation efforts, in this instance, resulted in a shift in the terrestrial arthropod community towards conditions observed in the undisturbed habitat. Terrestrial arthropod community composition data suggest that rehabilitation efforts resulted in an improvement in ecological integrity in this instance.

Significant differences in arthropod community composition between undisturbed and rehabilitated or reclaimed sites have been reported in several instances. Burger et al. (2003) observed differences in vegetation between restored and undisturbed coastal sage scrub communities accompanied by corresponding differences in arthropod communities. Significant differences in arthropod communities following disturbance and rehabilitation were also observed by Bisevac and Majer (1999), Webb et al. (2000), and Longcore (2003).

Vegetation Community Composition

Analysis of vegetation aerial cover data in this case confirmed that significant differences in vegetation community composition exist between all three habitats studied. Vegetation in the rehabilitated habitat does not mimic an undisturbed condition. However, some components of the vegetation community and related variables (e.g. diversity, total shrub cover, etc.) in the rehabilitated habitat more closely resembled conditions observed in the undisturbed habitat than in the weed-infested habitat. Vegetation in the rehabilitated habitat represented a stable plant community likely better able to prevent erosion, resist invasion of exotic weeds, and resist additional wildfires than a community dominated by *Bromus tectorum* would be.

Ground Cover

Analysis of ground cover data demonstrated that while ground cover characteristics of the weed-infested habitat differed significantly from what was observed in both the rehabilitated and undisturbed habitats, the undisturbed and rehabilitated habitats displayed virtually no difference in ground cover characteristics. Thus, ground cover data suggest that the rehabilitation efforts in this instance were effective in restoring some ecological components to conditions observed in an undisturbed system.

Evidence of a relationship between vegetation and arthropod communities was observed, however, the differences between the arthropod communities in the three habitats did not follow the same pattern as the vegetation communities (compare Figure 3, and Figure 4). The terrestrial arthropod community appears to be related to, but not completely tied to plant species composition. Rehabilitation in this case, apparently did restore some component of ecosystem functionality, as the rehabilitated habitat is now capable of supporting an arthropod community significantly different from the community observed in the weed-infested habitat, and more similar to the terrestrial arthropod community in an undisturbed habitat. The environmental variables studied (vegetation and ground cover) may have contributed to that restoration of function, but did not fully explain the phenomenon observed. Evaluation of only the vegetation community or ground cover characteristics would have been less informative in this case than including arthropod community data with the other indicators.

The results of the SIMPER routine allow identification of the measured variables that contribute most to dissimilarity between undisturbed, disturbed – weed-infested, and rehabilitated habitats. Rehabilitation techniques designed specifically to directly or indirectly influence these variables could be effective at restoring some components of ecological integrity. Further research is needed to identify proximate factors that impact arthropod and plant taxa, and other variables that contribute to dissimilarity between the undisturbed and weed-infested habitats. A better understanding of those influential factors could reveal additional rehabilitation measures that could improve ecological integrity.

The relationship described between the terrestrial arthropod community and the vegetation and ground cover data does not necessarily imply causation. That is, the vegetation or ground cover variables do not necessarily drive the terrestrial arthropod community, or vice versa. Because these variables are related, however, simultaneous manipulation of both vegetation and terrestrial arthropods is likely possible, and rehabilitation efforts designed to influence one component may impact the other as well.

Conclusion

Restoration of communities including populations of both plants and animals is often attempted through vegetation manipulation alone. The assumption behind this type of management is that if a plant community approximating an undisturbed or pre-disturbance condition can be provided, other characteristics of suitable habitat will develop and populations of taxa occupying higher trophic levels will recolonize the area thus resulting in eventual restoration of the entire system (Brady et al. 2002, Longcore 2003). This paradigm assumes a strong relationship between vegetation and higher trophic groups. Under that assumption it follows that if the vegetation community produced by restoration efforts differs significantly from an undisturbed condition, and all other variables are equal, the resultant community of taxa in higher trophic levels would be expected to differ significantly from the analogous community in an undisturbed area. Similarly, if no significant difference were observed in restored vs. undisturbed plant communities, the communities of higher trophic levels in each area would not be expected to differ significantly. Longcore (2003), however, observed a disconnect between a restored plant community and the arthropod community it supported, and cited similar results from other studies. In these studies, differences remained apparent in arthropod communities in revegetated vs. undisturbed sites.

This study provides evidence of a relationship between vegetation and arthropod communities, but does not completely support the idea that vegetation composition alone is responsible for eventual restoration of ecological integrity. That the terrestrial arthropod community in the rehabilitated habitat showed characteristics intermediate to the communities observed in the undisturbed and weed-infested habitats even though the vegetation did not follow that pattern suggests that rehabilitation by revegetating can be beneficial even if complete restoration of a plant community is not practical or possible. Such improvements in ecological integrity may be important intermediate steps on the way to complete restoration where that is the goal.

Evaluating the effects of disturbance and rehabilitation on ecological integrity with arthropod richness data alone was effective in this system, but yielded somewhat different results than when arthropod community composition was used as an indicator. Using both richness data and community composition data gave a more complete picture of conditions in the study site. Both vegetation and arthropod community data were effective indicators demonstrating similarities and differences between the habitats studied. Again, the results of these techniques differed to some extent, and including both vegetation and arthropod community data yielded a more complete understanding of conditions at the study site. Including multiple and diverse variables resulted in a better understanding of the effects of disturbance and rehabilitation and identified specific differences between the habitats studied. Additional study of these discrepancies could lead to improved rehabilitation techniques and thus increased likelihood of restoration of ecological integrity to disturbed systems.

Implications for Practice

- Reseeding native and exotic plant species can facilitate improvements in ecological integrity.
- Using multiple ecological indicators such as: terrestrial arthropod richness, terrestrial arthropod and vegetation community composition, and ground cover characteristics can yield a better understanding of a complex system than can any one indicator alone.

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Table 1 Arthropod abundance data in each habitat, each year.

	Weed-infested		Rehabilitated		Undisturbed		Total
Taxa	2003	2004	2003	2004	2003	2004	
Acari	15	24	17	13	43	16	128
Anabrus simplex Haldeman	77	88	17	12	1	1	196
Araneae	390	152	152	146	76	100	1016
Carabidae	16	35	1	3	0	0	55
Curculionidae	0	0	0	1	0	4	5
Formicidae	745	259	388	470	570	453	2885
Gryllidae	15	5	15	7	5	1	48
Isoptera	115	2	1	0	2	0	120
Machilidae	1	4	0	0	26	34	65
Mutillidae	2	0	9	0	21	1	33
Pseudoscorpiones	2	0	7	1	4	4	18
Rhaphidophoridae	14	11	50	28	52	84	239
Scorpionida	31	13	15	12	23	27	121
Solifugae	4	7	9	2	20	10	52
Staphylinidae	2	1	0	0	0	0	3
Stenopelmatidae	2	0	0	0	0	0	2
Blapstinus spp	72	21	1	2	2	4	102
Coniontis sp.	9	0	0	0	0	0	9
Edrotes ventricosus	1	0	0	0	0	0	1
Eleodes extricata	7	3	1	0	1	0	12
Eleodes hispilabris	19	10	17	8	12	2	68
Eleodes longicollis	1	2	0	0	0	3	6
Eleodes obscurus	11	6	15	7	7	2	48
Eusattus muricatus	1	0	0	0	0	0	1
Steriphanus	41	0	0	0	1	0	42
Total	1593	643	715	712	866	746	5275
Richness	24	17	16	14	17	16	25

Table 2 Contribution (%) of arthropod taxa to between habitat dissimilarity

Taxa	Undisturbed & Weed-infested	Undisturbed & Rehabilitated	Rehabilitated & Weed-infested
Anabrus simplex	12.71	8.99	10.18
Formicidae	9.9	12.73	14.51
Araneae	9.36	7.88	7.82
Blapstinus sp.	7.65	3.25	10.51
Rhaphidophoridae	7.58	6.42	5.27
Carabidae	7.18	2.92	7.43
Machilidae	6.72	14.75	1.88
Isoptera	4.74	1.32	5.91
Steriphanus sp.	3.83	0.76	5.31
Acari	3.25	5.46	2.93
Eleodes hispilabrus	3.11	4.48	2.1
Mutillidae	2.89	3.04	1.75
Eleodes extricata	2.83	1	3.62
Gryllidae	2.67	5.51	3.02
Pseudoscorpiones	2.34	3.06	1.89
Eleodes obscurus	2.32	4.98	3.09
Solifugae	2.16	4.87	2.53
Scorpiones	1.98	4.36	2.88
Eleodes longicollis	1.56	2.16	1.43
Coniontis sp.	1.53	0	1.93
Stenopelmatinae	1.12	0	1.43
Curculionidae	1.04	2.06	0.64
Staphylinidae	0.8	0	1.01
Eusattus muricatus	0.39	0	0.49
Edrotes ventricosa	0.35	0	0.44

Table 3 Arthropod data including average abundance of each taxon and contribution (%) of each taxon to dissimilarity between years.

Taxa	Average abundance 2003	Average abundance 2004	Contribution to dissimilarity 2003 & 2004
Formicidae	154.818	147.75	15.57
Araneae	56.182	49.75	8.25
Rhaphidophoridae	10.545	15.375	4.47
Acari	6.818	6.625	4.55
Scorpiones	6.273	6.5	3.35
Eleodes hispilabrus	4.364	2.5	4.27
Solifugae	3	2.375	3.24
Anabrus simplex	8.636	12.625	5.03
Eleodes obscurus	3	1.875	4.44
Mutillidae	2.909	0.125	6.72
Gryllidae	3.182	1.625	4.58
Blapstinus sp.	6.818	3.375	4.84
Pseudoscorpiones	1.182	0.625	3.19
Steriphanus sp.	3.818	0	4.92
Machilidae	2.455	4.75	3.4
Eleodes extricata	0.818	0.375	1.63
Carabidae	1.545	4.75	3.99
Coniontis sp.	0.818	0	1.6
Staphylinidae	0.182	0	0.84
Eleodes longicollis	0.091	0.625	2.25
Isoptera	10.727	0.25	5.52
Curculionidae	0	0.625	1.82
Stenopelmatinae	0.182	0.125	0.74
Eusattus muricatus	0.091	0	0.41
Edrotes ventricosa	0.091	0	0.37

Table 4 Average vegetation aerial cover (%) and standard errors (in parentheses) for the habitats.

	Undisturbed	Rehabilitated	Weed-infested
Picrothamnus desertorum Nutt.	-	0.008 (0.008)	-
Artemisia tridentata Nutt.	11.4 (2.074)	3.967 (1.416)	-
Atriplex canescens (Pursh) Nutt.	-	0.683 (0.626)	-
Atriplex confertifolia (Torr. & Frém.) S. Wats.	1.717 (0.898)	0.05 (0.05)	-
Ericameria nauseosa (Pallas ex Pursh) Nesom & Baird	-	4.983 (1.73)	-
Chrysothamnus viscidiflorus (Hook.) Nutt.	0.217 (0.173)	-	-
Shrub total	13.33 (2.282)	9.692 (2.292)	-
Phlox hoodii Richards.	-	0.1 (0.07)	-
Sphaeralcea munroana (Dougl. ex Lindl.) Spach ex Gray	-	-	0.017 (0.012)
Forb total	-	0.1 (0.07)	0.017 (0.012)
Agropyron cristatum L.	-	2.967 (0.604)	-
Elymus elymoides (Raf.) Swezey	0.075 (0.052)	0.3 (0.117)	-
Poa secunda J. Presl	0.008 (0.008)	1.6 (0.455)	-
Achnatherum hymenoides (Roemer & J.A. Schultes) Barkworth	0.45 (0.241)	0.008 (0.008)	-
Perennial grass total	0.533 (0.244)	4.875 (0.86)	-
Bromus tectorum L.	12.28 (2.158)	2.25 (0.816)	54.63 (3.076)
Ceratocephala testiculata (Crantz) Bess.	0.133 (0.029)	0.075 (0.023)	0.008 (0.008)
Salsola tragus L.	-	0.008 (0.008)	0.5 (0.199)
Sisymbrium altissimum L.	0.008 (0.008)	-	-
Annual weed total	12.42 (2.155)	2.333 (0.814)	55.13 (3.02)

Table 5 Contributions (%) of plant species to community dissimilarity between habitats

Species	Undisturbed & Weed-infested	Undisturbed & Rehabilitated	Rehabilitated & Weed-infested
Bromus tectorum L.	36.27	17.49	39.82
Artemisia tridentata Nutt.	30.93	12.67	11.98
Atriplex confertifolia (Torr. & Frém.) S. Wats.	12.16	9.76	0.91
Salsola tragus L.	6.25	0.4	4.14
Achnatherum hymenoides (Roemer & J.A. Schultes) Barkworth	5.1	4.14	0.36
Chrysothamnus viscidiflorus (Hook.) Nutt.	3.26	2.93	0
Ceratocephala testiculata (Crantz) Bess.	2.7	1.17	1.37
Elymus elymoides (Raf.) Swezey	1.36	3.16	2.23
Sphaeralcea munroana (Dougl. ex Lindl.) Spach ex Gray	0.98	0	0.7
Poa secunda J. Presl	0.54	8.5	7.14
Sisymbrium altissimum L.	0.45	0.41	0
Ericameria nauseosa (Pallas ex Pursh) Nesom & Baird	0	18.22	14.52
Agropyron cristatum L.	0	13.9	11.06
Atriplex canescens (Pursh) Nutt.	0	4.68	3.71
Phlox hoodii Richards.	0	2.13	1.69
Picrothamnus desertorum Nutt.	0	0.45	0.36

Table 6 Ground cover (%) with standard errors (in parentheses).

Category	Undisturbed	Rehabilitated	Weed-infested
Bare ground	29.79 (0.037)	40 (0.033)	4.375 (0.013)
Litter	55 (0.039)	45 (0.032)	88.54 (0.021)
Plant crown	3.75 (0.009)	3.542 (0.009)	6.458 (0.018)
Cryptogam	11.46 (0.025)	11.46 (0.019)	0.208 (0.002)

Table 7 Ground cover contribution (%) to between habitat dissimilarity data

Category	Undisturbed & Weed-infested	Undisturbed & Rehabilitated	Rehabilitated & Weed-infested
Bare ground	32.42	26.22	35.22
Cryptogam	28.35	30.87	24.34
Plant crown	19.86	20.87	17.16
Litter	19.38	22.03	23.28

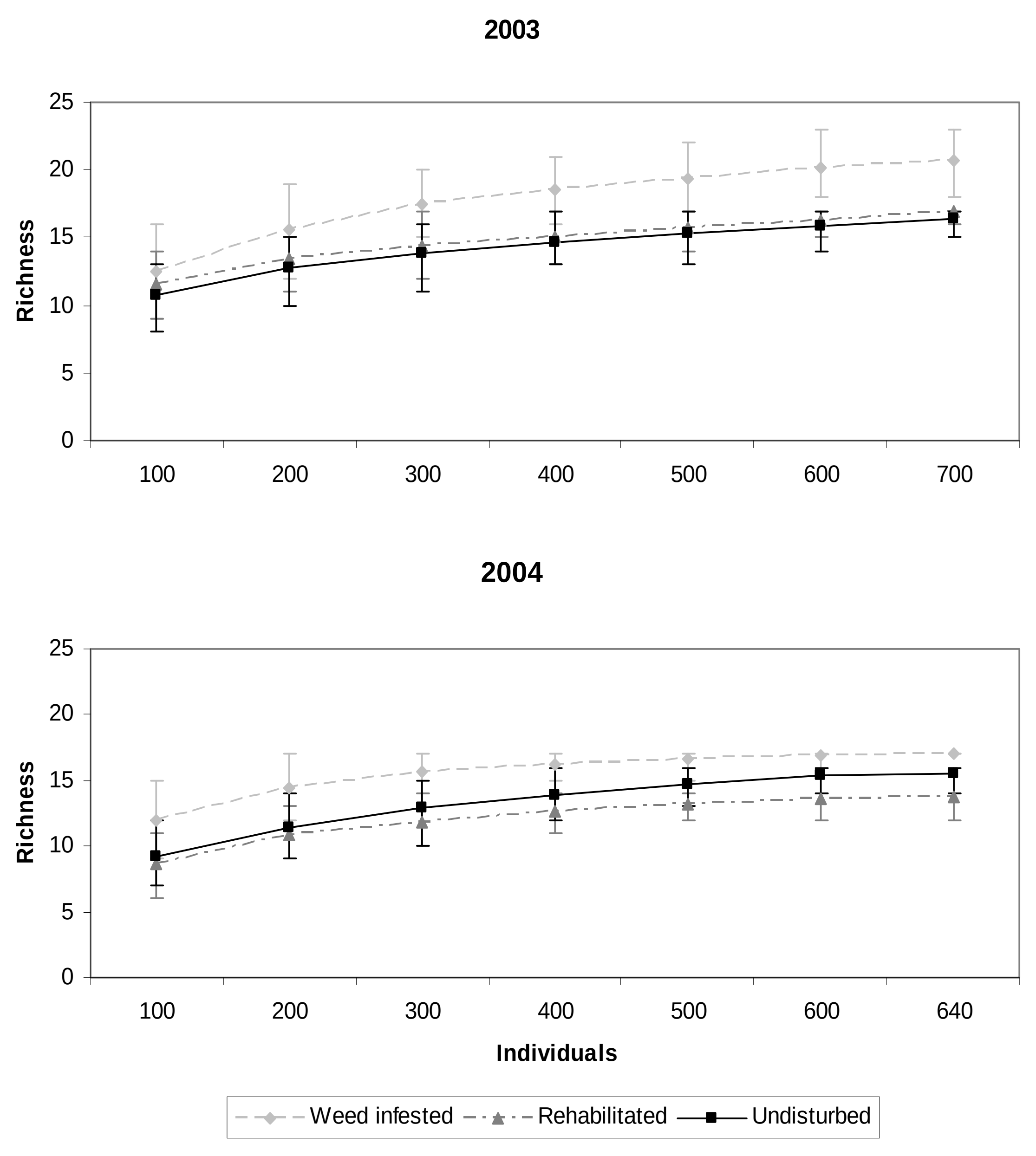

Figure 1 Individual based rarefaction curves with 95% confidence intervals comparing differences in terrestrial arthropod taxon richness between habitats (weed-infested , rehabilitated , and undisutrbed) in 2003 and 2004.

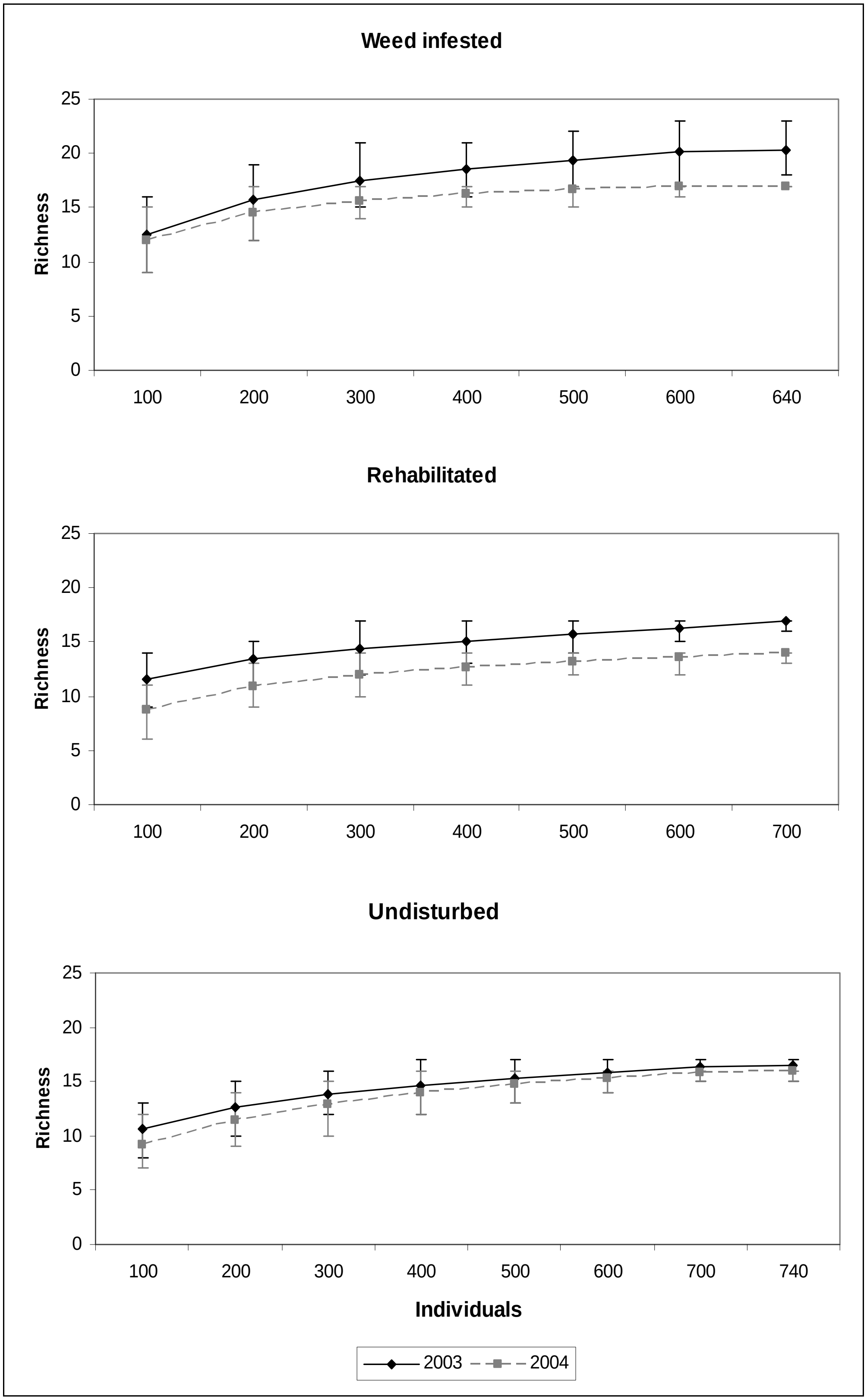

Figure 2 Individual based rarefaction curves with 95% confidence intervals comparing differences in terrestrial arthropod taxon richness between years (2003 and 2004) in three different habitat conditions (weed-infested, rehabilitated, and undisturbed).

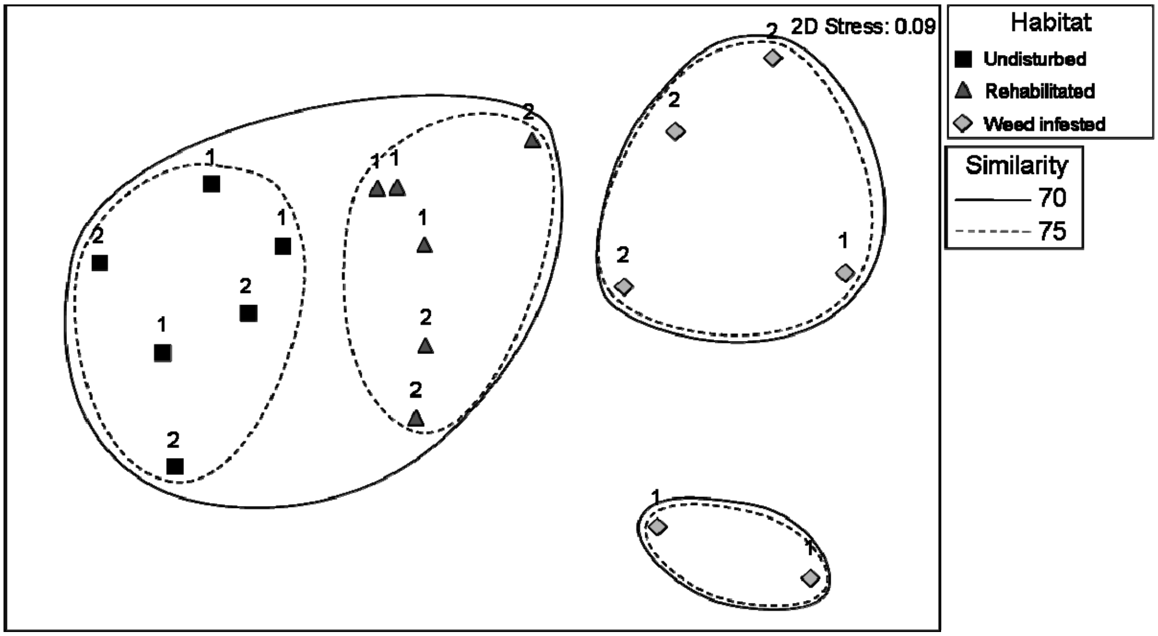

Figure 3 NMDS plot of terrestrial arthropod community composition data with superimposed similarity levels (70% and 75%).

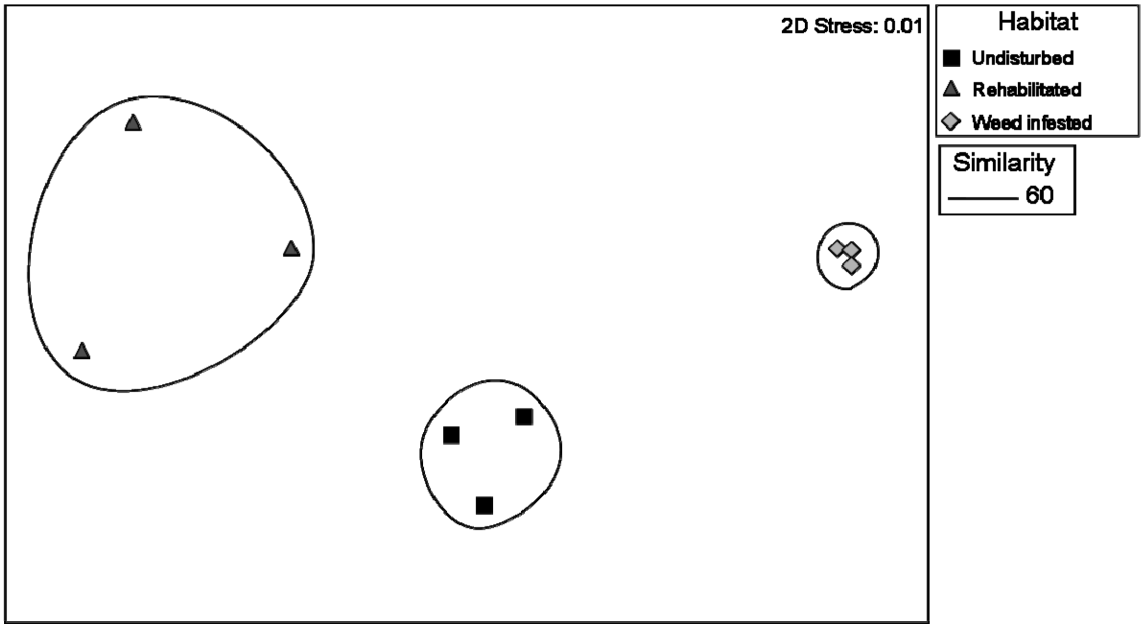

Figure 4 NMDS plot of vegetation community structure (using aerial cover data) from weed-infested, rehabilitated, and undisturbed habitats with 60% similarity level superimposed.

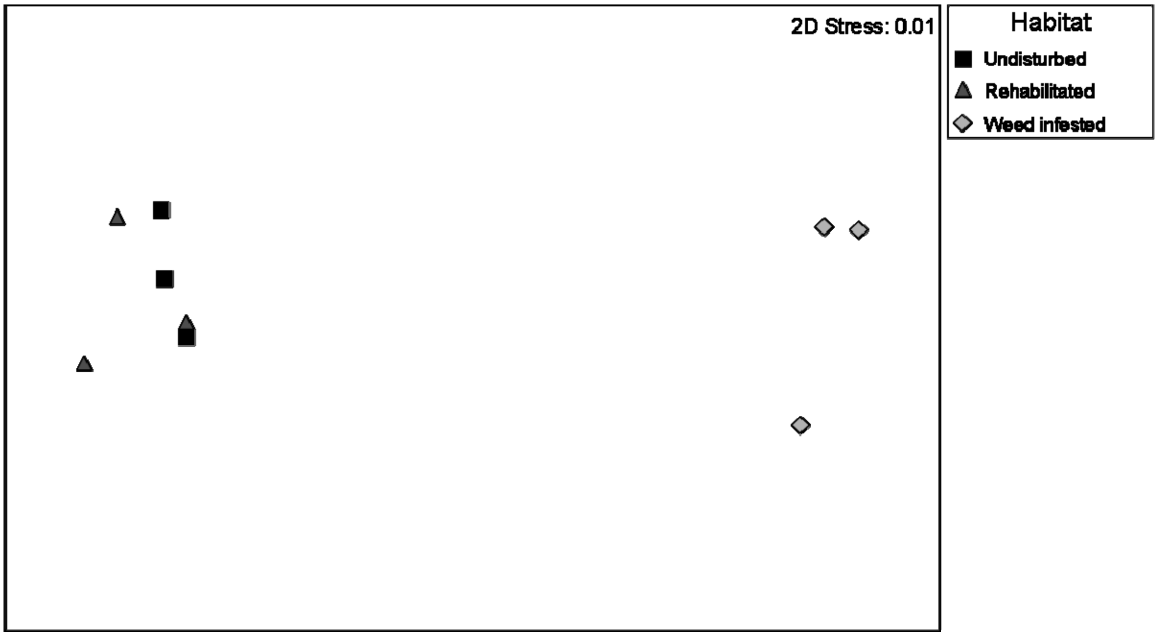

Figure 5 NMDS plot of ground cover data from weed-infested, rehabilitated, and undisturbed habitats