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Sonoran Desert Network
Tucson, Arizona

Evaluating Management of Lehmann lovegrass (*Eragrostis lehmanniana*) at Coronado National Memorial Final Report

Natural Resources Report NPS/IMR/SODN-006
PMIS #97333





SONORAN DESERT NETWORK
Inventory and Monitoring Program

ON THE COVER
Eragrostis lehmanniana-dominated grasslands at Coronado National Memorial.
Photograph by Theresa Mau-Crimmins, Sonoran Desert Network I&M.

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Evaluating Management of Lehmann lovegrass (*Eragrostis lehmanniana*) at Coronado National Memorial
Final Report

Technical Report NPS/IMR/SODN-006
PMIS #97333

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Intermountain Region
Denver, Colorado

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Executive Summary

This study was a pre-eradication assessment to determine the efficacy of a large-scale *E. lehmannian* removal at Coronado NM via herbicide. This study was funded through a NPS Biological Resources Management Division grant, PMIS#97333. Objectives for this project were to 1) evaluate the effects of the application of the common herbicide glyphosate to particularly afflicted grassland sites at Coronado National Memorial; 2) assess the response of semi-desert grassland to the removal of the dominant nonnative grass, *E. lehmanniana* (Lehmann lovegrass); and 3) develop specific recommendations for exotic plant management and restoration of semi-desert grasslands at Coronado NM. Additionally, the seed bank was sampled six times throughout the course of the study to determine the availability of native plant seeds for reestablishment of the original semi-desert grassland community. A final objective to test a selective, grass-specific herbicide (sethoxydim) was added following the initiation of the project.

Repeated application of glyphosate (RoundUp) herbicide to *E. lehmanniana* did have a significant impact on treatment plots in this study, as exhibited in the cover of *E. lehmanniana* and in the community composition of the treated plots. Following removal of *E. lehmanniana*, substantial increases in the cover of annual species, forb species, and native species were observed. These increases are not attributable to the increase in one or two species, but rather to broader shifts in community composition. Nearly all species occupying the plots following treatment were native species. No treatment effects were evident on plots treated with sethoxydim herbicide.

There is potential for restoring this site to a community less dominated by *E. lehmanniana*, however it would require a large time and monetary commitment. Repeated application of glyphosate (RoundUp) herbicide to *E. lehmanniana* did have a significant impact on *E. lehmanniana* cover. However, follow-up application of herbicide was required several times over the course of the study, as new *E. lehmanniana* individuals germinated continually from the seed bank. Seed bank trials revealed differences in the species richness and composition of samples only in the final season tested, suggesting a possible shift in seed bank with continual above-ground *E. lehmanniana* removal. Control of *E. lehmanniana* could be possible, but would be most feasible with the use of mechanized equipment.

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Introduction

The management of areas invaded by nonnative species is a daunting challenge facing park managers, as the ecological ramifications of these invasions conflicts with both specific park management goals and the NPS mandate set forth in the Organic Act of 1916. Invasions of nonnative species can have drastic consequences for ecosystem functional (Vitousek, and Walker 1989, Le Maitre et al. 1996) and structural attributes, including decreased biodiversity of native plants and animals (Bock et al. 1986, Wilcove et al. 1998), altered fire regimes (Mack and D'Antonio 1998), and in many cases, extinctions of native species (Pimm et al. 1995). Under some conditions, particularly afflicted sites may exceed "ecological thresholds" beyond which re-establishment of native communities by succession alone may be not be feasible; rather, manipulative management and/or restoration will be required (Archer 1989). For management and restoration efforts to be successful, preliminary ecological data explicitly linked to proposed management practices is crucial. Unfortunately, such data is seldom available (Underwood 1995).

Lehmann lovegrass (*Eragrostis lehmanniana* Nees) is an introduced perennial bunchgrass that is increasingly dominating semi-desert grasslands and savannas of the American Southwest (McPherson and Weltzin 2000), including many parks in the Sonoran and Chihuahuan Deserts. In 2002, the Sonoran Desert Network Inventory and Monitoring Program (SODN) documented foliar cover of Lehmann lovegrass exceeding 75% on many grassland sites at Coronado National Memorial (CORO), among the highest concentrations ever measured in the region (SODN, unpl. data). This infestation presents an enormous management challenge for CORO. Decreasing species richness of native flora and fauna associated with the increasing dominance of Lehmann lovegrass has been widely documented (Cable 1971, Bock et al. 1986, Medina 1988, McPherson et al. 2001). In addition, Lehmann lovegrass encroachment has dramatically affected fire regimes of semi-desert grasslands, typically increasing fire frequency, intensity, and spread (McPherson 1995). The combined effects of modified competitive hierarchies and altered fire regimes has dramatic consequences for grassland/savanna ecosystems generally, and Palmer agave (*Agave palmeri*) populations in particular. Ensuring the persistence of Palmer agave in semi-desert grasslands/savannas is a leading resource management concern at Coronado NM, as the nectar of this species is a required food resource for the endangered lesser long-nosed bat (*Leptonycteris curasoae*) that roosts in the park.

Under contemporary land use and climate, *E. lehmanniana* has been predicted to continue to spread (Cable 1971, Anable et al. 1992, McClaran and Anable 1992, Robinett 1992, Mau-Crimmins et al. in press). Without effective management, it appears likely that this exotic plant will continue to spread and eventually dominate low- and mid-elevations of Coronado National Memorial, to the detriment and possible exclusion of the native grassland and savanna communities. As such, park managers at CORO and other southwestern parks must consider active management strategies for containing and restoring affected areas.

Objectives

It is imperative to understand the likely effects of a management action before it is undertaken. In the absence of this knowledge, the efficacy and feasibility of any restoration project is unknown. In addition, the "law of unintended consequences" may apply, as the effect of a management action could actually exacerbate the problem. For example, efforts to control and reduce an exotic plant species may initiate unexpected and undesirable feedbacks, such as favoring other (perhaps more noxious) exotic species, stimulating recruitment of new exotic plant seedlings, or drastically reducing plant cover to the detriment of wildlife and soil resources. This project was a tactical biological study to evaluate potential management scenarios for controlling *Eragrostis lehmanniana* (Lehmann lovegrass) and restoring semi-desert grassland at CORO. Specifically, our objectives for this project were to:

1. Evaluate the effects of the application of herbicide to particularly afflicted grassland sites at Coronado National Memorial.

2. Assess the response of semi-desert grassland to the removal of the dominant nonnative grass, *E. lehmanniana* (Lehmann lovegrass).

3. Develop specific recommendations for exotic plant management and restoration of semi-desert grasslands at CORO.

A related issue is the availability of native plant seeds (including rare species such as Palmer agave) for reestablishment of the original semi-desert grassland community. Sustained *E. lehmanniana* domination may have removed sufficient germinable native seeds from the seedbank that recolonization may require dispersal from offsite. If this is the case, restoration without active seeding of native species (appropriate seed sources for most species do not exist) may take much longer, as the margins of the *E. lehmanniana* dominated area would need to be colonized first. To evaluate the current availability of native propagules, we sampled the seed bank.

A final objective was added following the initiation of the project. Because glyphosate (RoundUp) is a non-selective herbicide, any plants coming in contact with it are likely to be killed. Shielding native, non-target plants from herbicide spray keeps the native portion of the plant community intact, but is impractical for large-scale restoration efforts. It was suggested that an additional study component be added, where a selective, grass-specific herbicide be applied to *E. lehmanniana* (Terry Cacek, *pers. comm.* 2005). Because this objective was added after the commencement of the project, less data are available for these study plots.

Methods

Species information

Eragrostis lehmanniana was introduced from Africa and officially released by the U.S. Soil Conservation Service (currently the NRCS) to stabilize soils and provide cattle forage (Cox et al. 1984). This species spreads aggressively to dominate perennial grass composition, establishes in new areas without disturbance, and produces copious amounts of seed that disperse by wind and water (Anable et al. 1992). In the 50 years following its introduction, this grass occupied twice the area to which it was originally sown (Cox and Ruyle 1986), and is predicted to spread to areas far beyond its current range (Mau-Crimmins et al. in press). *E. lehmanniana* seed planted throughout Arizona, New Mexico, and Texas can be traced to a single plant (Crider 1945). Recent research has shown that genetic variation in U.S. *E. lehmanniana* populations does exist, though it is unknown whether this variation is the result of the U.S. population undergoing mutation and genetic drift or due to genotypic variability present in the introduced individual (Schussman 2002).

Site description

The study site was located within the Montezuma Allotment at Coronado National Memorial near Hereford, Arizona (31.33°N, 110.23°W; elevation 1,500 m). Cattle grazed this allotment from at least 1929 until 1990 (University of Arizona Student Chapter, Society for Range Management 1995). The soil at this site is a Lanque sandy loam (thermic Pachic Haplustoll), with a slightly acid to slightly alkaline pH (6.1-7.8) and a depth of greater than 150 cm (Denny and Peacock 2000). The soils are alluvium derived from granite (Denny and Peacock 2000). Annual precipitation at Coronado NM is 52.5 cm (WRCC 2005). Average daytime temperatures are 16°C. Maximum temperatures reach 32°C in June and July, and winter minimum temperatures reach approximately 0°C in January and February (WRCC 2005).

Field methods

The experiment used a randomized block design. Fourteen plots were established at CORO in FA03. Plot locations were selected to maximize cover by *E. lehmanniana* and minimize presence of other species. A buffer of at least 1 m separated plots. At each site, one-half of the plots were randomly assigned the RoundUp (glyphosate) removal treatment; the remaining plots were untreated. In the spring of 2005, 7 additional plots were located and assigned the Vantage removal treatment.

In the spring (April and May) of 2003, plant cover was estimated in all plots using the point-intercept method (Greig-Smith 1983). Five parallel transects spaced 1 m apart were placed in each plot. Aerial cover was recorded every 10 cm along each transect, resulting in 250 points per plot. In addition, all species observed in a plot but not encountered using the point-intercept method also were recorded. Species were identified

and assigned native or nonnative status; annual, biennial, or perennial habit; and graminoid, forb/herb, shrub, tree, or vine growth form according to the PLANTS database (http://plants.usda.gov). A few species had insufficient characteristics for identification but were clearly distinct from other species in the plots and were labeled as morphospecies. Plant names follow the Integrated Taxonomic Information System (ITIS) convention (http://www.itis.usda.gov).

Immediately following the plot inventories, the non-selective herbicide glyphosate (RoundUp) was applied to the glyphosate treatment plots to remove *E. lehmanniania.* Prior to treatment, all non-target forbs and grasses were identified and shielded from treatment by covering with plastic bags. The glyphosate was applied in a low-volume broadcast application using hand-held spray equipment at a rate of 45 ml/ha. Dead *E. lehmanniana* litter was not removed, as a previous study suggested *E. lehmanniana* does not replace itself on herbicide-treated plots with the canopy left intact (Sumrall et al. 1991). Follow-up treatments to kill *E. lehmanniana* plants which subsequently established in the glyphosate treatment plots were applied in July and August of 2003 and again in May and July of 2004. Plots were again sampled in the fall (August-September) of 2003, and again in the spring and fall of 2004 and 2005. Vantage treatment plots were sampled in the spring of 2005, then treated using the Vantage herbicide immediately following. In these plots, no non-target plants were covered; herbicide was applied using a broadcast application using hand-held spray equipment covering the entire plot. The Vantage treatment plots were again sampled in the fall of 2005. From this point forward, spring seasons are referred to as SP03, SP04, and SP05 and fall seasons are named FA03, FA04, and FA05.

In addition to measures of species cover, standing live and dead biomass and surface litter was measured in areas adjacent to the study plots. Twenty 1.0 m x 0.5 m quadrats were placed in random locations within 1 m of study plots. The samples were sorted into standing biomass by species and litter. The samples were dried for 48 hours at 68°C and weighed to the nearest 0.1 g. Biomass samples were collected in FA02, SP03, FA03, SP04, FA04, SP05, and FA05.

The seed banks of the control and glyphosate treatment plots were sampled in May, July, and September of 2003 and 2004 (denoted SP03, SU03, FA03 and SP04, SU04, and FA04) in an attempt to capture peaks in seed abundance. The emergence technique (Brown 1992) was used to assess the composition of the soil seed banks. Four cores measuring 7 cm in diameter and 3 cm deep were randomly located and sampled from each of the study plots. Samples were combined by plot in a single labeled paper bag. Soil samples were stored in paper bags until air dry. Each sample was sieved through a #10 mesh to remove rocks and other debris and spread approximately 1 cm thick onto sterilized potting soil in four 100 cm^2 pots. Seedling trays were kept in a greenhouse and watered daily. The greenhouse was cooled in summer and heated in winter, but experienced considerable daily and seasonal variation in temperature. To ensure conditions were appropriate for native species we expected to see, seed of three common grasses (*Bouteloua gracilis* (Willd. ex Kunth) Lag. ex Griffiths, *Bouteloua*

curtipendula (Michx.) Torr., *Digitaria californica* (Benth.) Henr.) were added to pots containing only the sterilized growing medium.

When seedlings could be identified, they were counted and pulled to minimize competition within pots. The top layer of the soil samples was stirred approximately four weeks following initiation to encourage further germination. Seed bank samples were maintained in the greenhouse until emergence ceased, typically after six months or less. Seedlings recorded for the four pots per plot were combined for further analysis.

To characterize basic soil properties for the study site, soil samples consisting of six cores 7 cm in diameter and 5 cm depth were collected outside of plots in July 2004. Two such samples were collected at CORO. The samples were combined and air-dried in paper bags. The Soil, Water, and Plant Analysis Laboratory (Tucson, AZ) analyzed the samples for pH, cation exchange capacity, phosphorus, potassium, total organic carbon, and texture.

Precipitation data

Daily precipitation data for the National Weather Service Cooperative Observer Station located at Coronado NM was downloaded from the National Climatic Data Center (NOAA 2006). Precipitation was totaled for each site for winter months (December-January) and summer months (June-September) of 2003, 2004, and 2005 to capture the bimodal precipitation pattern evident in southern Arizona.

Statistical analyses: Aboveground vegetation

To test whether there was a significant glyphosate treatment effect on the plant communities of the study plots, several separate repeated-measures multivariate analysis of variance (MANOVA) tests were performed with the parameter of interest measured at each sampling date treated as a different dependent variable in each test. For the separate tests, parameters included percent plant cover, relative percent native cover, relative percent forb cover, relative percent annual cover, and species richness. Treatment was the independent variable. Repeated-measures data were analyzed with MANOVA due to potential autocorrelation between consecutive sampling dates (O'Brien and Kaiser, 1985). If necessary, data were transformed with the square-root transformation prior to analysis to increase homogeneity of variances (Sokal and Rohlf, 1995). This transformation removed skew. To minimize spatial autocorrelation and to account for not meeting the assumption of sphericity, the Greenhouse-Geisser adjustment was applied to "within-subjects" effects (Greenhouse and Geisser, 1959; Littell *et al.*, 1992). MANOVA analyses were performed using SAS v8.02 (SAS Institute, 2001).

To test for a Vantage treatment effect, several separate ANOVA tests were performed with percent plant cover, relative percent native cover, relative percent forb cover, relative percent annual cover, and species richness measured in FA05 (post-treatment) as the dependent variable. Treatment (control, glyphosate, and Vantage) was

the independent variable. The Tukey-Kramer HSD test for multiple comparisons was used to control the overall error rate.

Aboveground community analyses

Following the removal of rare species (contributing <5%), Bray-Curtis similarity coefficients (Bray and Curtis 1957) were calculated for aboveground abundance data using a square-root transformation to balance the influence of dominant and rare species (Clarke and Warwick 2001). Analysis of similarity (ANOSIM) was then used to test for changes in community composition following experimental treatments. Within a particular season, communities of treated plots at a site were compared to control plots at the same site. ANOSIM was also used to test for differences from season to season within each site and treatment combination. ANOSIM is a non-parametric permutation procedure based on the ranking coefficients derived from similarity matrices. ANOSIM calculates a test statistic (R) typically ranging from 0 to 1, where R=0 when there is an equivalent degree of similarity between and within groups, and where R=1 when all replicates within groups are more similar than any replicates from different groups (Clarke and Warwick 2001). The statistic was recomputed 5,000 times/test using a Monte Carlo permutation (Clarke and Warwick 2001).

When differences in species assemblages were detected using ANOSIM, the particular species responsible for differences in overall community composition were determined using the 'Similarity Percentages' (SIMPER) routine. SIMPER is a technique that identifies the species responsible for particular aspects of a multivariate plot by considering the contribution of species to both the average similarity within groups as well as the average dissimilarity between groups (Clarke and Warwick 2001). All community analyses were performed using PRIMER software v5.2.8 (PRIMER-E Ltd. 2001).

Seed bank abundance

To test whether there was a significant treatment effect on the abundances of germinable seedlings in the seed bank of the control and glyphosate treatment plots, I performed MANOVA with each sampling date treated as a different dependent variable. Dependent variables included total seeds germinated, percent native seedlings, percent graminoid seedlings, and percent perennial seedlings. The independent variable was treatment. Repeated-measures data were analyzed with MANOVA due to potential correlation between consecutive sampling dates. "Total number of seedlings" was transformed with a square-root transformation prior to analysis and all other variables were transformed using the arcsine square-root transformation to increase homogeneity of variances. To minimize spatial autocorrelation, the Greenhouse-Geisser adjustment was applied to "within-subjects" effects (Greenhouse and Geisser 1959, Littell et al. 1992). To test whether treatment had an effect on the percent of seedlings that were *E. lehmanniana*, I used MANOVA. Percent of seedlings that were *E. lehmanniana* was the dependent variable and treatment was the independent.

Seed bank community analyses

Seedlings counted were totaled for each plot and sampling event. The percent of the total seedlings for each plot and sampling event was then calculated by species. Following the removal of rare species (contributing <5%), Bray-Curtis similarity coefficients were calculated for seed bank data using a square-root transformation to balance the influence of dominant and rare species. ANOSIM was then used to test for changes in community composition following experimental treatments. Within a particular season, communities of treated plots at a site were compared to control plots at the same site. ANOSIM was also implemented to test for differences from season to season within each site and treatment combination. When differences in species assemblages were detected using ANOSIM, the particular species underlying differences in overall community composition were determined using SIMPER.

Comparison of abundance and soil seed bank datasets

To compare the composition of species represented in both the seed bank and the vegetation survey, the data were combined into one matrix and analyzed using non-metric multi-dimensional scaling (NMS) based on Bray-Curtis similarity values. Rare (contributing <5%) species we removed and similarity values were calculated for data using a square-root transformation. NMS is a non-parametric ordination technique that constructs a configuration of the sample data such that similar samples are located in close proximity in ordination space (Clarke and Warwick 2001).

Biomass data

Analysis of variance (ANOVA) was used to determine whether season had an effect on the biomass of *E. lehmanniana* over the course of the study. Abundance in kilograms per hectare of *E. lehmanniana* was the dependent variable and site was the independent variable. The Tukey-Kramer HSD test for multiple comparisons was used to control the overall error rate. A visual estimation of residual plots indicated that distributions were not substantially skewed. Therefore, analyses were performed on untransformed data.

Results

Aboveground vegetation statistical analyses

Over the course of the study, 79 different species were recorded within study plots (Table 1). Of these, only *E. lehmanniana*, *Macroptilium gibbosifolium*, and *Sida abutifolia* are not native to the U.S.

Table 1. Plant species observed in study plots at Coronado NM.

Species
Acacia angustissima (P. Mill.) Kuntze
Acacia greggii Gray
Ambrosia confertiflora DC.
Aristida sp.
Aristida ternipes Cav.
Aristida ternipes Cav. var. *ternipes*
Baccharis pteronioides DC.
Baccharis sarothroides Gray
Bothriochloa barbinodis (Lag.) Herter
Bouteloua chondrosioides (Kunth) Benth. ex S. Wats.
Bouteloua curtipendula (Michx.) Torr.
Bouteloua eriopoda (Torr.) Torr.
Bouteloua gracilis (Willd. ex Kunth) Lag. ex Griffiths
Bouteloua hirsuta Lag.
Calliandra eriophylla Benth.
Chaetopappa ericoides (Torr.) Nesom
Chamaecrista nictitans (L.) Moench
Chamaesyce hyssopifolia (L.) Small
Chenopodium fremontii S. Wats.
Cirsium sp. P. Mill.
Cirsium undulatum (Nutt.) Spreng.
Conyza canadensis (L.) Cronq.
Croton pottsii (Klotzsch) Muell.-Arg. var. *pottsii* (Klotzsch) Muell.-Arg.
Dasylirion wheeleri S. Wats.
Dichelostemma capitatum (Benth.) Wood ssp. *capitatum*
Digitaria californica (Benth.) Henr.
Diodia teres Walt.
Eragrostis intermedia A.S. Hitchc.
Eragrostis lehmanniana Nees
Erigeron divergens Torr. & Gray
Eriochloa aristata Vasey
Eriogonum wrightii Torr. ex Benth.
Euphorbia sp.
Evolvulus alsinoides (L.) L.
Evolvulus arizonicus Gray

Evolvulus nuttallianus J.A. Schultes
Gilia sp.
Gnaphalium sp.
Gnaphalium palustre Nutt.
Gomphrena caespitosa Torr.
Gomphrena sonorae Torr.
Guilleminea densa (Humb. & Bonpl. ex Willd.) Moq.
Helianthus annuus L.
Heteropogon contortus (L.) Beauv. ex Roemer & J.A. Schultes
Heterotheca subaxillaris (Lam.) Britt. & Rusby
Hybanthus verticillatus (Ortega) Baill.
Ipomoea sp.
Isocoma tenuisecta Greene
Lepidium sp.
Lotus greenei Ottley ex Kearney & Peebles
Lotus sp.
Lycurus phleoides Kunth
Lycurus setosus (Nutt.) C.G. Reeder
Machaeranthera gracilis (Nutt.) Shinners
Machaeranthera sp.
Machaeranthera tanacetifolia (Kunth) Nees
Macroptilium gibbosifolium (Ortega) A. Delgado
Mimosa aculeaticarpa Ortega var. *biuncifera* (Benth.) Barneby
Mitracarpus breviflorus Gray
Mollugo verticillata L.
Muhlenbergia sp.
Nissolia wislizeni (Gray) Gray
Plantago patagonica Jacq.
Portulaca halimoides L.
Portulaca pilosa L.
Portulaca umbraticola Kunth
Pseudognaphalium canescens (DC.) W.A. Weber
Pseudognaphalium leucocephalum (Gray) A. Anderb.
Senecio sp.
Sida abutifolia P. Mill.
Sida spinosa L.
Solanum elaeagnifolium Cav.
Sporobolus cryptandrus (Torr.) Gray
Stephanomeria pauciflora (Torr.) A. Nels.
Talinum aurantiacum Engelm.
Talinum brevicaule S. Wats.
Tetraclea coulteri Gray
Urochloa arizonica (Scribn. & Merr.) O. Morrone & F. Zuloaga
Zinnia grandiflora Nutt.

For the comparison between control and glyphosate-treated plots (5 seasons), three of the dependent variables tested (total plant cover, relative percent forb cover, and relative percent native cover) exhibited a highly significant two-way interaction between season and treatment ($p \leq 0.0003$; Table 2). The main effect of sampling season was significant for the dependent variables relative percent annual cover and species richness for the comparison between control and glyphosate-treated plots.

Table 2. Repeated measures MANOVA for aboveground vegetation analyses at Coronado NM in southeastern Arizona. The factors are: Season = post-treatment sampling season (Fall 2003, Spring 2004, Fall 2004, Spring 2005, Fall 2005) and Treatment = glyphosate, control. Greenhouse-Geisser adjustment was used to correct for autocorrelation among repeated measure factor Season.

Response Variable	Source	DF	F value	*p*
Total plant cover	Season*Treatment	3, 31	8.23	0.0003
Percent forb cover	Season*Treatment	3, 33	11.13	<.0001
Percent native cover	Season*Treatment	3, 41	14.04	<.0001
Species richness	Season	3, 39	7.71	0.0003

For the comparison between control, glyphosate-treated, and sethoxydim-treated plots (1 season),

The one-way ANOVA revealed that every variable tested differed significantly as a function of treatment ($F_{2,16} = 11.541, p \leq .0008$; Table 3). In addition, multiple comparisons tests revealed that for every variable tested, glyphosate-treated plots differed significantly from control and sethoxydim-treated plots, but control and sethoxydim-treated plots did not differ for any variables tested (Table 2).

Table 3. Analysis of variance tests and multiple comparisons tests for aboveground vegetation analyses Coronado NM. Means with the same letter are not significantly different ($p < .05$).

Response Variable	*F*	*p*	Control	Glyphosate treatment	Sethoxydim treatment
Total plant cover	11.541	0.0008	a	b	a
Percent forb cover	22.951	< .0001	a	b	a
Percent native cover	68.099	< .0001	a	b	a
Percent *E. lehmanniana* cover	82.147	< .0001	a	b	a
Species richness	13.774	0.0002	a	b	a

The interaction of treatment and sampling season had a significant "within subjects" effect on total plant cover ($p = 0.0003$; Table 2) for the comparison between control and glyphosate-treated plots (5 seasons), Total cover in control plots dropped slightly in both seasons in 2004 and then increased in fall of 2005 (Figure 1). Following treatment in spring 2003, total cover dropped markedly in glyphosate-treated plots and

remained much lower than in control plots in all seasons post-treatment but spring of 2005.

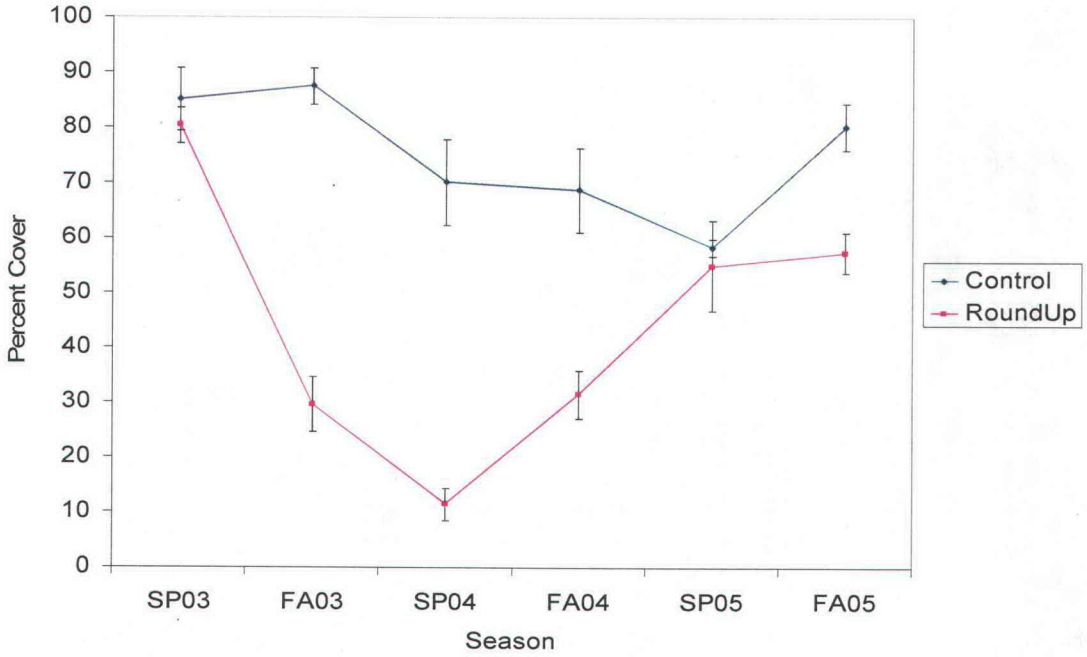


Figure 1. Effect of treatment on total plant cover (mean±SE) before (SP03) and after removing *E. lehmanniana* from study plots (control and glyphosate-treated) at Coronado NM. SP = Spring, FA = Fall; sampling seasons 2003, 2004, and 2005.

The interaction of treatment and sampling season had a significant "within subjects" effect on both relative percent forb cover and relative percent native cover for the comparison between and glyphosate-treated plots (5 seasons; $p < .0001$; Table 2). Both variables exhibited similar patterns. Relative percent forb and native cover remained very low (less than 10%) in control plots throughout the course of the study. Relative percent forb and native cover fluctuated greatly in glyphosate-treated plots, showing the greatest peaks in the fall seasons (Figures 2 and 3). Both variables exhibited the greatest peaks in fall 2005.

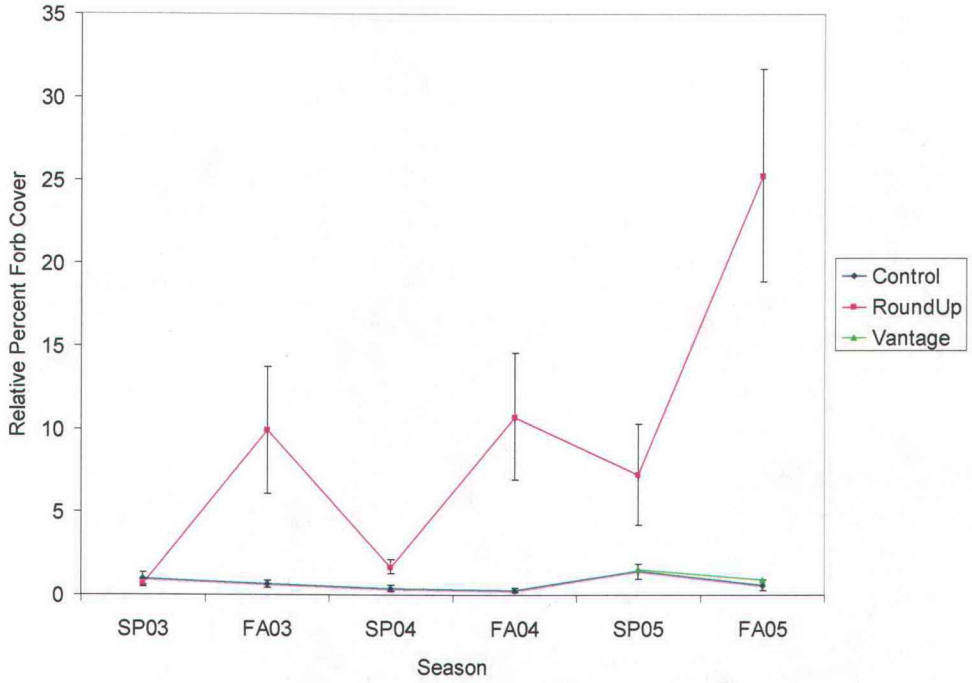


Figure 2. Effect of treatment on relative percent forb cover (mean±SE) before (SP03) and after removing *E. lehmanniana* from study plots (control and glyphosate-treated) at Coronado NM. SP = Spring, FA = Fall; sampling seasons 2003, 2004, and 2005.

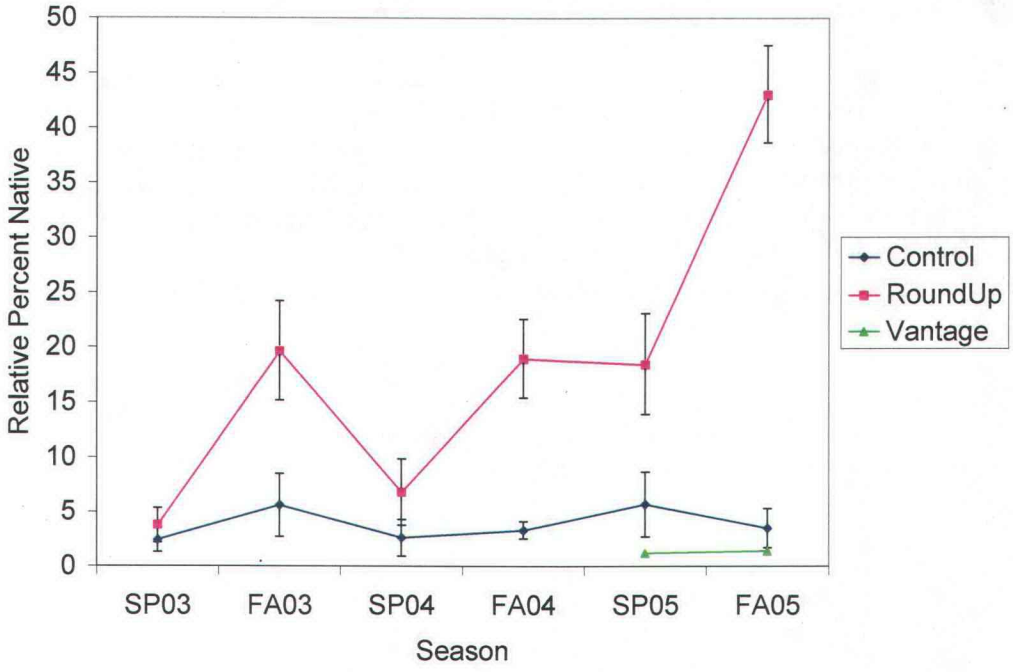


Figure 3. Effect of treatment on relative percent native cover (mean±SE) before (SP03) and after removing *E. lehmanniana* from study plots (control and glyphosate-treated) at Coronado NM. SP = Spring, FA = Fall; sampling seasons 2003, 2004, and 2005.

The main effect of sampling season was significant for species richness ($p < 0.040$; Table 2) for the comparison between and glyphosate-treated plots (5 seasons). Species richness fluctuated between 8 and 12 species per plot over the course of the study; fall values were consistently higher than spring values (Figure 4).

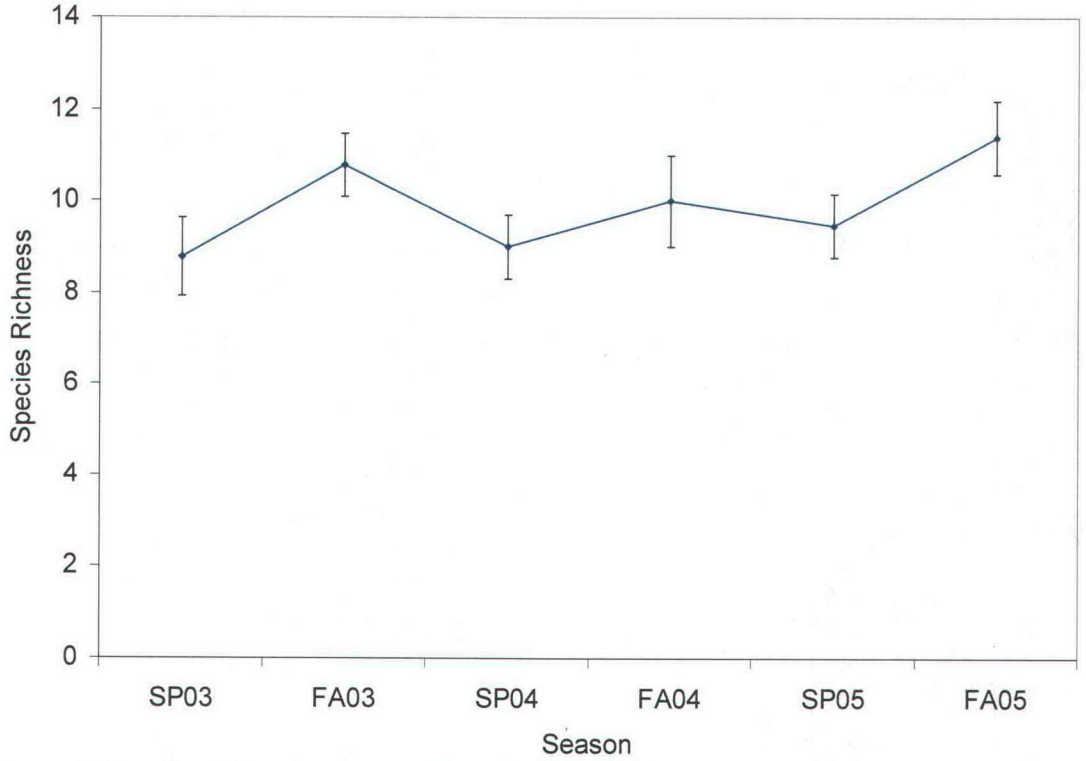


Figure 4. Species richness (mean±SE) before (SP03) and after removing *E. lehmanniana* from study plots (control and glyphosate-treated) at Coronado NM. SP = Spring, FA = Fall; sampling seasons 2003, 2004, and 2005.

Aboveground vegetation – community analyses

Control and glyphosate-treated plots were not significantly different pre-treatment (SP03) or in the first season post-treatment (FA03; Table 4). However, control and glyphosate-treated plots were significantly different from a community perspective in every successive season. Control and sethoxydim-treated plots were not different in either spring or fall 2005 (Table 4).

Table 4. ANOSIM and SIMPER results discriminating within-season species assemblages. R = test statistic indicating relative dissimilarity (0 –1, with 1 = identical composition between groups). Percentages reflect proportion of dissimilarity attributable to each species. "*" denotes significant ($P < 0.05$) dissimilarity between groups. Percentages reflect proportion of dissimilarity attributable to each species.

Season	Global/Pairwise Test	R	*p*	Species Differentiation- SIMPER

				(Percent of Dissimilarity)
SP03	Control vs. Glyphosate	-0.007	0.406	n/a
FA03	Control vs. Glyphosate	1.0	0.143	n/a
SP04	Control vs. Glyphosate	0.568	**0.002***	*E. lehmanniana* (60%), *Calliandra eriophylla* (11%), *Bouteloua* sp. (6%)
FA04	Control vs. Glyphosate	0.555	**0.001***	*E. lehmanniana* (35%), *C. eriophylla* (14%), *Molluga verticillata* (8%), *Evolvulus nuttallianus* (7%), *Nissolia wislizeni* (5%)
SP05	Control vs. Glyphosate	0.609	**0.002***	*E. lehmanniana* (42%), *C. eriophylla* (16%), *Erigeron divergens* (8%), *Plantago patagonica* (7%), *Gnaphalia* sp. (6%)
	Control vs. Vantage	0.044	0.238	n/a
	Glyphosate vs. Vantage	0.615	**0.002***	*E. lehmanniana* (46%), *C. eriophylla* (17%), *E. divergens* (9%), *P. patagonica* (7%), *Gnaphalia* sp. (6%)
FA05	Control vs. Glyphosate	0.677	**0.001***	*E. lehmanniana* (28%), *C. eriophylla* (13%), *E. divergens* (13%), *M. verticillata* (11%)
	Glyphosate vs. Vantage	0.684	**0.001***	*C. eriophylla* (20%), *E. lehmanniana* (15%), *E. divergens* (12%), *Bouteloua gracilis* (11%), *Acacia angustissima* (9%), *N. wislizeni* (7%), *Sida abutifolia* (6%)
	Control vs. Vantage	-0.053	0.711	n/a

Results of SIMPER analyses indicated that the differences between control and both types of treated plots in all post-treatment seasons were mainly due to the lack of *E. lehmanniana* in treated plots. Differences were also attributed to increases in *Calliandra eriophylla* and a handful of native, annual forb species including *Molluga verticillata*, *Evolvulus nuttallianus*, *Plantago patagonica*, and *Erigeron divergens*. Some differences were also due to *Nissolia wislizeni*, a native perennial herb known only to occur in Cochise County, AZ within the United States.

Within control plots, no seasons were significantly different from one another (Table 5). Within glyphosate-treated plots, there were no differences detected between the first three sampling seasons. However, the remaining three seasons were all significantly different from one another (Table 5). Spring 2003 was different from spring 2004, but spring 2004 was not different from spring 2005. Conversely, no difference was detected between fall 2003 and fall 2004, but fall 2004 and fall 2005 were significantly different. These differences were mainly attributable to increases in *Calliandra eriophylla*, a native perennial shrub, and in *Erigeron divergens*, *Mollugo verticillata*, native annual species, over the course of the study. Finally, the two seasons sampled for sethoxydim-treated plots were not significantly different (Table 5).

Table 5. ANOSIM and SIMPER results discriminating within-treatment species assemblages. R = test statistic indicating relative dissimilarity (0 –1, with 1 = identical composition between groups). Percentages reflect proportion of dissimilarity attributable to each species. "*" denotes significant ($P < 0.05$) dissimilarity between groups. Percentages reflect proportion of dissimilarity attributable to each species.

Site/ Treatment	Global/ Pairwise Test	R	*p*	Species Differentiation- SIMPER (Percent of Dissimilarity)
Control	Global	0.042	0.135	n/a
	SP03 - FA03	-0.011	0.478	n/a
	FA03 - SP04	0.081	0.141	n/a
	SP04 - FA04	0.026	0.310	n/a
	FA04 - SP05	0.041	0.263	n/a
	SP05 - FA05	0.056	0.231	n/a
	SP03 - SP04	0.005	0.422	n/a
	SP04 - SP05	-0.079	0.843	n/a
	FA03 - FA04	0.066	0.216	n/a
	FA04 - FA05	0.067	14.6	n/a
Glyphosate	Global	0.392	**0.001***	n/a
	SP03 - FA03	0.946	0.125	n/a
	FA03 - SP04	-0.143	1.0	n/a
	SP04 - FA04	0.2	0.086	*C. eriophylla* (18%), *E. lehmanniana* (13%), *M. verticillata* (10%), *E. nuttallianus* (9%), *N. wislizeni* (6%), *Eriogonum wrightii* (6%)
	FA04 - SP05	0.328	**0.015***	*C. eriophylla* (17%), *E. lehmanniana* (11%), *E. divergens* (8%), *P. patagonica* (8%), *M. verticillata* (7%), *E. nuttallianus* (6%), *Gnaphalia* sp. (6%)
	SP05 - FA05	0.313	**0.026***	*C. eriophylla* (16%), *E. divergens* (14%), *E. lehmanniana* (11%), *M. verticillata* (11%), *P. patagonica* (6%), *Bouteloua gracilis* (6%)
	SP03 - SP04	0.557	**0.001***	*E. lehmanniana* (60%), *C. eriophylla* (12%)
	SP04 - SP05	0.156	0.11	n/a
	FA03 - FA04	-0.116	0.75	n/a
	FA04 - FA05	0.202	0.085	*C. eriophylla* (15%), *E. divergens* (13%), *M. verticillata* (11%), *E. lehmanniana* (7%)
Vantage	SP05 - FA05	0.123	0.072	n/a

Seed bank statistical analyses

In seed bank samples taken from control and glyphosate-treated plots, 1,489 seedlings germinated over the course of the study period. Of these, 50% (725) were *E. lehmanniana* seedlings. 32 species were recorded for CORO (Table 6). Of these, four species were nonnative, and only *E. lehmanniana* and *Sisymbrium irio* are noxious nonnative species. All three native grasses seeded to sterilized growing medium

(*Bouteloua gracilis*, *Bouteloua curtipendula*, and *Digitaria californica*) germinated, demonstrating that conditions within the greenhouse were appropriate for these grass species.

Table 6. Plant species observed in seed bank samples taken from control and glyphosate-treated plots at Coronado NM.

Species
Androsace occidentalis Pursh
Aristida ternipes Cav.
Bouteloua aristidoides (Kunth) Griseb.
Bouteloua curtipendula (Michx.) Torr.
Chamaesyce micromera (Boiss. ex Engelm.) Woot. & Standl.
Conyza canadensis (L.) Cronq.
Eragrostis cilianensis (All.) Vign. ex Janchen
Eragrostis intermedia A.S. Hitchc.
Eragrostis lehmanniana Nees*
Eragrostis sp.
Eriastrum diffusum (Gray) Mason
Erigeron divergens Torr. & Gray
Gnaphalium palustre Nutt.
Herniaria hirsuta L. ssp. *cinerea* (DC.) Coutinho
Laennecia coulteri (Gray) Nesom
Leptochloa panicea (Retz.) Ohwi ssp. *brachiata* (Steudl.) N. Snow
Mitracarpus breviflorus Gray
Mollugo verticillata L.
Muhlenbergia sp.
Nuttallanthus texanus (Scheele) D.A. Sutton
Oxalis corniculata L.
Plantago patagonica Jacq.
Portulaca halimoides L.
Portulaca pilosa L.
Portulaca umbraticola Kunth
Pseudognaphalium arizonicum (Gray) A. Anderb.
Sisymbrium irio L.*
Sporobolus cryptandrus (Torr.) Gray
Uro*chloa arizonica* (Scribn. & Merr.) O. Morrone & F. Zuloaga
Veronica peregrina L.
unknown grass

* Denotes non-native, invasive species.

The two-way interaction between site and sampling date had a significant "within subjects" effect on seed bank species richness ($p = 0.0368$; Table 7). In seasons SP03 and SU04, glyphosate-treated plots exhibited significantly higher species richness than control plots; in other seasons, species richness was not discernibly different.

Table 7. Repeated measures MANOVA for seed bank analyses at Coronado NM in southeastern Arizona. The factors are: Season (Spring 2003, Summer 2003, Fall 2003, Spring 2004, Summer 2004, Fall 2004) and Treatment = glyphosate, control. Greenhouse-Geisser adjustment was used to correct for autocorrelation among repeated measure factor Season.

Response Variable	Source	DF	F value	*P*
Germinating seeds	Season	3, 36	12.78	<.0001
Percent graminoid seeds	Season	3, 32	6.11	0.0020
Percent perennial seedlings	Season	3, 32	5.74	0.0031
Percent native seedlings	Season	4, 45	3.191	0.0217
Seed bank species richness	Season*Treatment	3, 35	3.07	0.0368
Percent of seedlings that were *E. lehmanniana*	Season	4, 32	1.14	0.0158

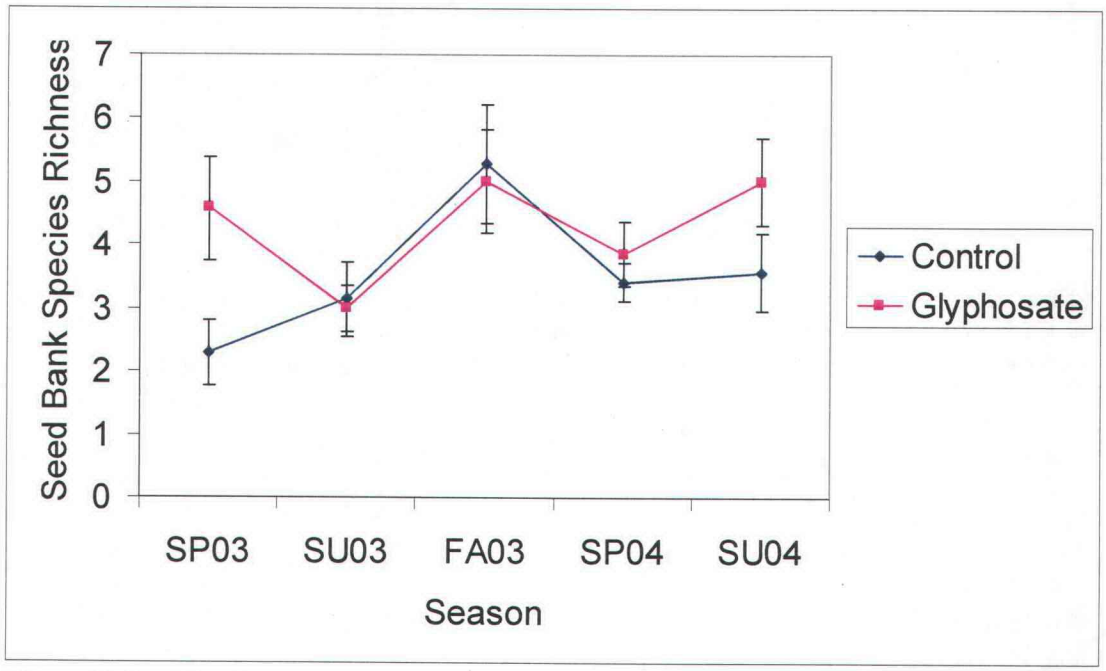


Figure 5. Seed bank species richness (mean±SE) from study plots (control and glyphosate-treated) before (SP03) and after removing *Eragrostis lehmanniana* from Coronado NM. SP = Spring, SU = summer, FA = Fall; sampling seasons 2003, 2004, and 2005.

For all other variables tested (total seeds germinated, percent native seedlings, percent graminoid seedlings, percent perennial seedlings, and percent of seedlings that were *E. lehmanniana*), the main factor of sampling season was significant. Total seeds germinated showed a large increase in the final season tested (SU04) over all other seasons (Figure 6). Percent graminoid seedlings and percent perennial species showed similar patterns; for both variables, values were consistent with the exception of FA03, which was significantly lower than all other seasons (Figures 7 and 8). Percent native seedlings showed the opposite pattern, with FA03 showing a large spike over all other

seasons (Figure 9). Percent of germinating seedlings that were *E. lehmanniana* did not fluctuate greatly over the course of the study.

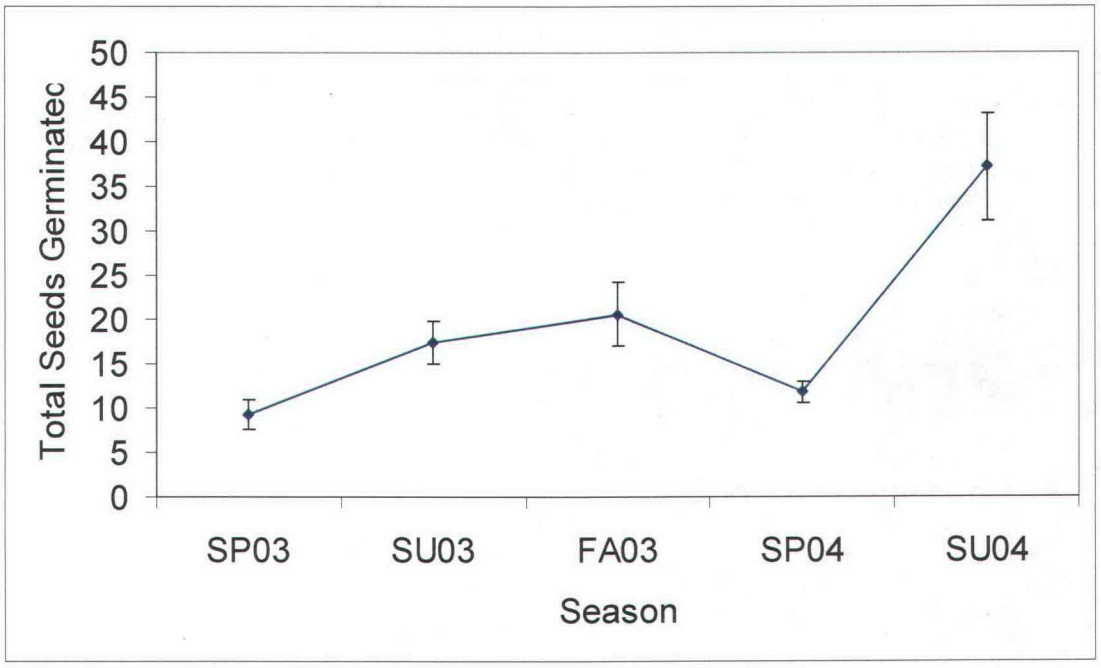


Figure 6. Total seeds germinated (mean±SE) from study plots (control and glyphosate-treated) before (SP03) and after removing *Eragrostis lehmanniana* from Coronado NM. SP = Spring, SU = summer, FA = Fall; sampling seasons 2003, 2004, and 2005.

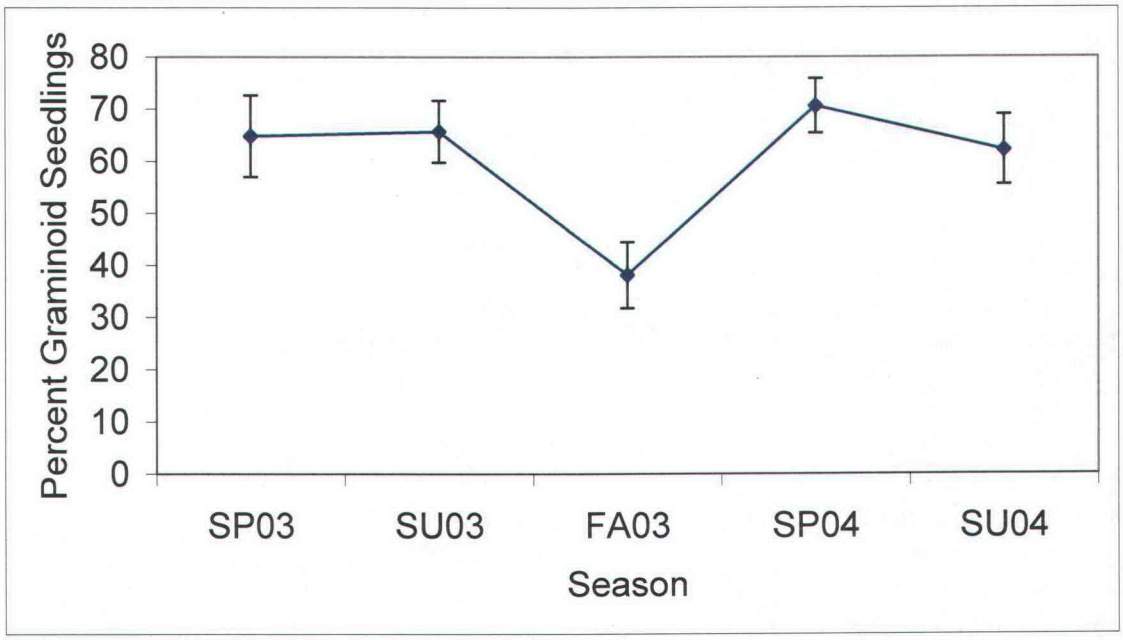


Figure 7. Percent graminoid seeds germinated (mean±SE) from study plots (control and glyphosate-treated) before (SP03) and after removing *Eragrostis lehmanniana* from

Coronado NM. SP = Spring, SU = summer, FA = Fall; sampling seasons 2003, 2004, and 2005.

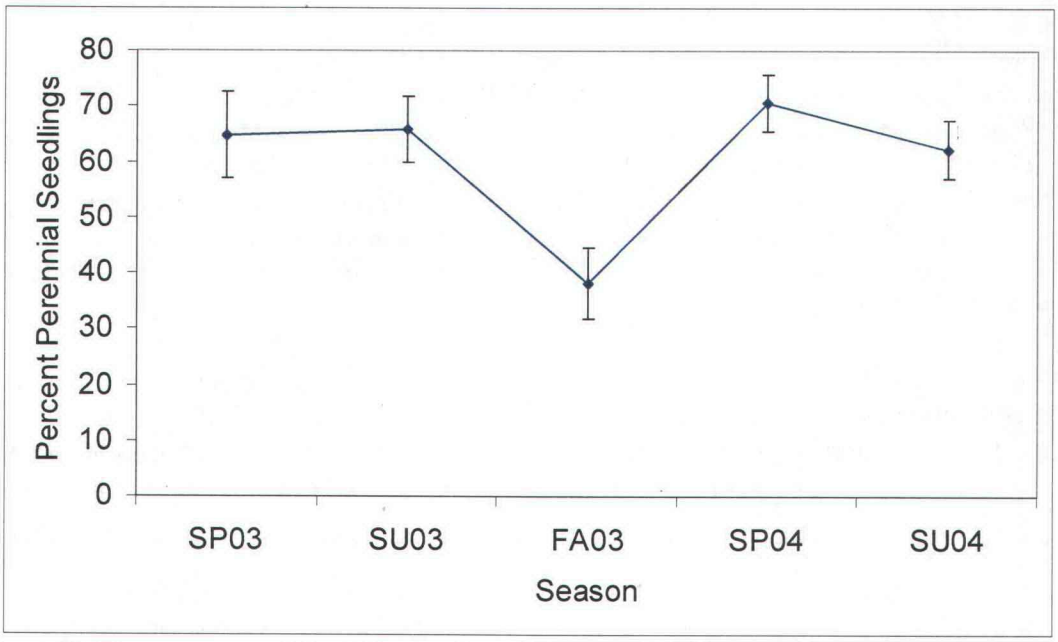


Figure 8. Percent perennial seeds germinated (mean±SE) from study plots (control and glyphosate-treated) before (SP03) and after removing *Eragrostis lehmanniana* from Coronado NM. SP = Spring, SU = summer, FA = Fall; sampling seasons 2003, 2004, and 2005.

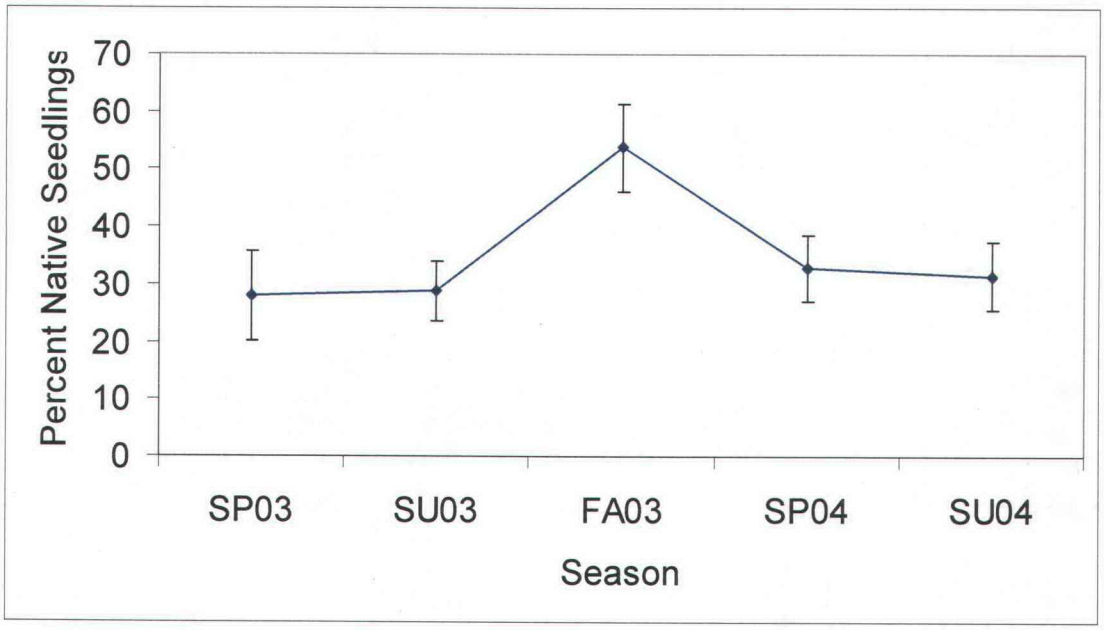


Figure 9. Percent native seeds germinated (mean±SE) from study plots (control and glyphosate-treated) before (SP03) and after removing *Eragrostis lehmanniana* from Coronado NM. SP = Spring, SU = summer, FA = Fall; sampling seasons 2003, 2004, and 2005.

Seed bank community composition

Seed bank samples from both control and glyphosate-treated plots differed from summer to fall 2003 and from fall 2003 to spring 2004 (Table 8). Summer 2004 was also different from fall 2004 in control plots. SIMPER analyses indicated that the main differences between seed bank sampling seasons for control plots can be attributed to fluctuations in the abundances of *E. lehmanniana*, *Pseudognaphalium arizonicum* (Gray) A. Anderb., *Gnaphalium palustre* Nutt., *Mollugo verticillata*, and *Oxalis corniculata* L., all native annual forb species with the exception of *E. lehmanniana*. Seed bank samples from treated plots varied slightly in composition of the same species as for control plots, as well as *Erigeron divergens* (Table 8).

Table 8. ANOSIM and SIMPER results discriminating within-treatment seedbank species assemblages. R = test statistic indicating relative dissimilarity (0 –1, with 1 = identical composition between groups). "*" denotes significant ($P < 0.05$) dissimilarity between groups. Percentages reflect proportion of dissimilarity attributable to each species.

Site/ Treatment	Global/ Pairwise Test	R	*p*	Species Differentiation- SIMPER (Percent of Dissimilarity)
Control	Global	0.173	0.001	n/a
	SP03-SU03	-0.015	0.369	n/a
	SU03-FA03	0.255	**.03***	*Pseduognaphalium arizonicum* (8%), *Eragrostis lehmanniana* (7%), *Gnaphalium palustre* (6%)
	FA03-SP04	0.242	**.031***	*P. arizonicum* (12%), *Mollugo verticillata* (6%), *Oxalis corniculata* (6%), *G. palustre* (6%), *E. lehmanniana* (6%)
	SP04-SU04	-0.017	0.554	n/a
	SU04-FA04	0.344	**.005***	*P. arizonicum* (8%), *E. lehmanniana* (7%), *O. corniculata* (6%), *Plantago patagonica* (6%)
Glyphosate	Global	0.229	0.001	n/a
	SP03-SU03	0.046	0.258	n/a
	SU03-FA03	0.227	**.003***	*G. palustre* (9%), *E. lehmanniana* (8%), *P. arizonicum* (7%), *O. corniculata* (5%)
	FA03-SP04	0.526	**.004***	*P. arizonicum* (12%), *G. palustre* (9%), *E. lehmanniana* (7%), *M. verticillata* (7%), *Erigeron divergens* (5%), *O. corniculata* (5%)
	SP04-SU04	0.146	0.098	n/a
	SU04-FA04	0.144	0.071	n/a

The seed banks of treated and untreated plots only differed for the SU04 sampling period (Table 9). SIMPER results indicated differences in the abundances of *Mollugo verticillata*, *Oxalis corniculata*, *Erigeron divergens*, *Pseudognaphalium arizonicum*, and *Eragrostis intermedia* A.S. Hitchc. to account for the significant differences between samples taken from control and treated plots in SU04 (Table 9). In addition to differences in these species, the percent of germinating seeds that were *E. lehmanniana* was

markedly different between the two treatments (79% for samples from control plots; 44% for samples from treated plots).

Table 9. ANOSIM and SIMPER results discriminating within-site/treatment combination seed bank species assemblages between treatments. R = test statistic indicating relative dissimilarity (0 –1, with 1 = identical composition between groups). "*" denotes significant ($P < 0.05$) dissimilarity between groups. Percentages reflect proportion of dissimilarity attributable to each species.

Season	Global/Pairwise Test	R	*p*	Species Differentiation- SIMPER (Percent of Dissimilarity)
SP03	Global	0.597	**.001***	n/a
	CORO-C v. CORO-H	0.007	0.329	n/a
SU03	Global	0.659	**.001***	n/a
	CORO-C v. CORO-H	0.078	0.22	n/a
FA03	Global	0.725	**.001***	n/a
	CORO-C v. CORO-H	- 0.055	0.697	n/a
SP04	Global	0.631	**.001***	n/a
	CORO-C v. CORO-H	-0.14	0.92	n/a
SU04	Global	0.76	**.001***	n/a
	CORO-C v. CORO-H	0.228	**.015***	*M. verticillata* (7%), *O. corniculata* (5%), *Erigeron divergens* (5%), *Pseudognaphalium arizonicum* (5%), *Eragrostis intermedia* (5%)

Comparison of abundance and soil seed bank datasets

The non-metric multi-dimensional scaling ordination illustrates significant compositional dissimilarities between the seed bank and above-ground plant communities at Coronado NM. The seed bank sample community and the aboveground community are each clustered, with very little overlap (Figure 10). This suggests that despite the season sampled, communities germinating from seed bank samples do not represent the aboveground communities. These plots include all sampling seasons together; this demonstrates that there is no substantial relationship between seed bank and aboveground plant abundances in any of the seasons sampled and no evidence that a lag relationship exists.

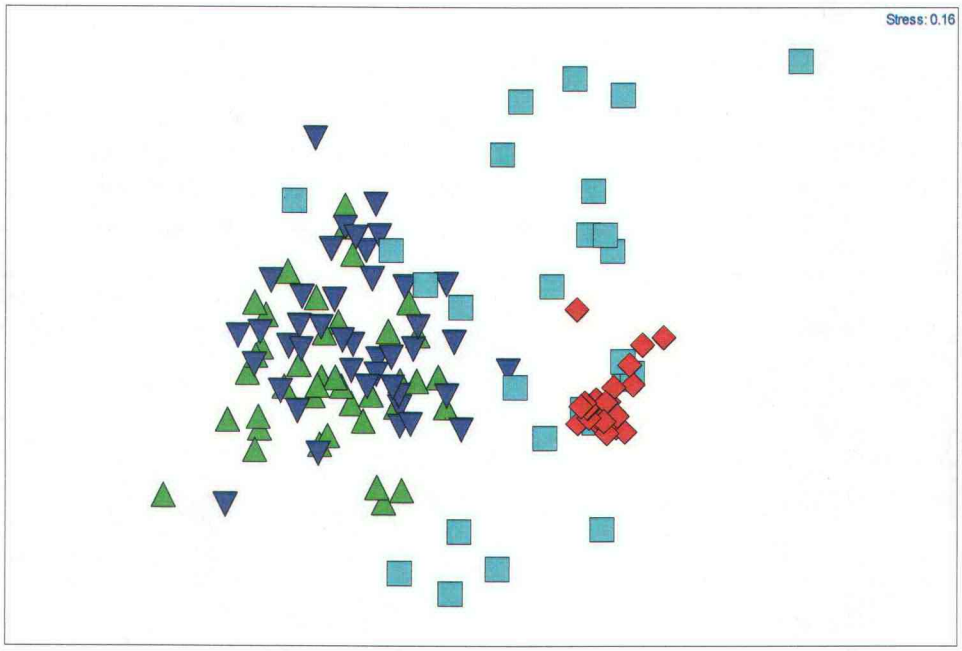


Figure 10. Non-metric multi-dimensional scaling plot of above-ground plant community and seed bank community at Coronado NM. Green triangles represent samples of seed banks from control plots; blue triangles are seed bank samples from treated plots. Red diamonds represent above-ground communities in control plots; light blue squares are above-ground communities in treated plots.-treated plots, and red diamonds are above-ground samples from control plots.

Of the 79 species observed in the aboveground vegetation in control and glyphosate treatment plots, 16 were germinated from seed bank samples. An additional sixteen species were germinated from soil samples that were not observed in aboveground vegetation. Of the species residing in the seed bank not expressed in aboveground vegetation, all but 3 species were natives, and all but 2 species were annuals. Five species were graminoids; the rest were forb species.

Aboveground biomass from field sites

The one-way ANOVA revealed that no season differed significantly from any other season regarding *E. lehmanniana* biomass (Figure 11). Other species which were abundant at CORO included *Calliandra eriophylla* (338 kg/ha; 95% CI: 176 to 498 kg/ha averaged over 6 sampling periods) and *Bouteloua eripoda* (Torr.) Torr. (8 kg/ha; 95% CI: 0 to 18 kg/ha).

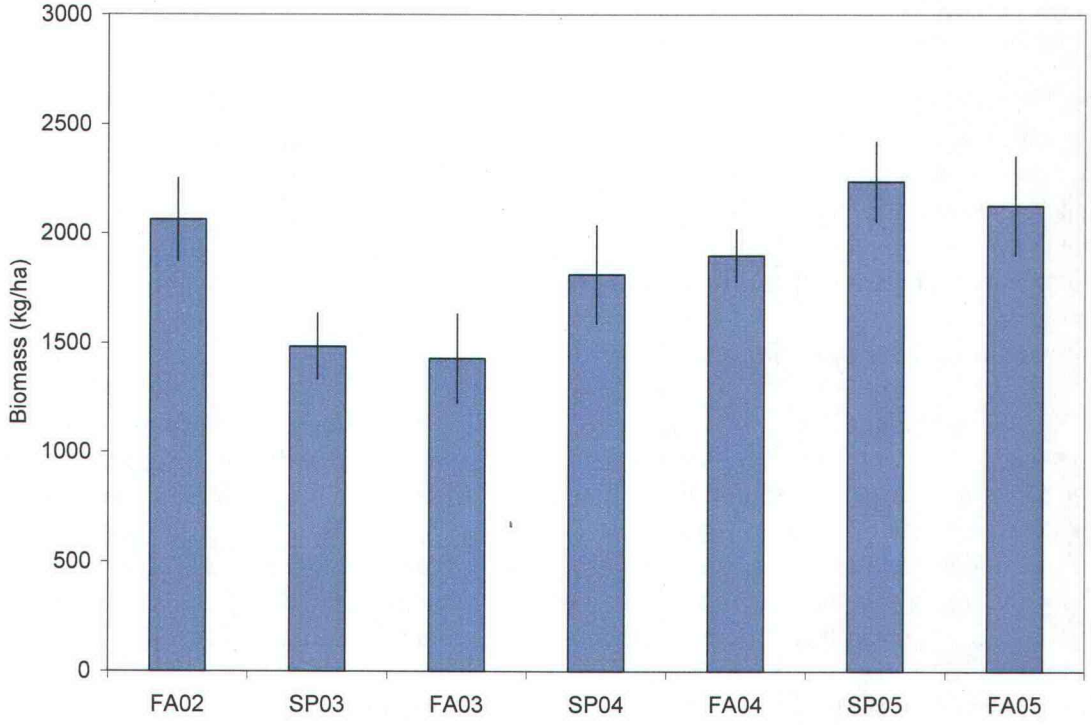


Figure 11. Biomass (mean±SE) of *E. lehmanniana* at Coronado NM over the course of the study. SP = Spring, FA = Fall; sampling seasons 2003, 2004, and 2005.

Precipitation data

Seasonal precipitation totals ranged between 5.7 and 33.7 cm over the course of the study (Table 10). Lowest seasonal precipitation was recorded for December 2002 - January 2003; highest seasonal precipitation was recorded for June – September 2003. Summer and winter totals were rather consistent across the three years (Table 10); the total was highest in 2003 and lowest in 2004.

Table 10. Seasonal precipitation totals (in centimeters) for NWS Cooperative Observer Station located at Coronado NM, Hereford, AZ, USA.

	2003	**2004**	**2005**
Winter (Dec-Jan)	5.7	7.3	11.7
Summer (Jun-Sep)	33.7	25.6	23.9
Total	**39.4**	**33.0**	**35.6**

Discussion

This study was a pre-eradication assessment to determine the efficacy of a large-scale *E. lehmannian* removal at Coronado NM via herbicide. The goal of a pre-eradication assessment is to determine not only the efficacy of a removal effort, but also the potential for undesired effects to be realized. The information gained through this study is important because it lays the groundwork for proactive, rather than reactive, ecosystem management. Proactive management anticipates the changes in structure and function resulting from large-scale changes such as invasion by nonnative species.

Treatment effect - Glyphosate

Repeated application of glyphosate (RoundUp) herbicide to *E. lehmanniana* did have a significant impact on treatment plots in this study, as exhibited in the cover of *E. lehmanniana* and in the community composition of the treated plots. From a community perspective, treated plots were significantly different from control plots every season post-treatment, demonstrating that the treatment did have a notable effect (Table 4). These findings are in agreement with other studies demonstrating the effectiveness of glyphosate for controlling *E. lehmanniana* (Biedenbender and Roundy 1996).

Glyphosate-treated plots at Coronado NM showed immediate responses to the removal of *E. lehmanniana*. As expected, removing *E. lehmanniana* resulted in significant drops in total plant cover in treated plots, which rebounded following the initial post-treatment reduction. The removal also resulted in a significant increase in species richness that was sustained for the duration of the experiment. This finding is consistent with several other removal experiments where removal of a dominant species resulted in increases in species richness (Abul-Fatih and Bazzaz 1979, Hils and Vankant 1982, Armesto and Pickett 1985, Farnsworth and Meyerson 1999). Responses to the complete removal of *E. lehmanniana* could potentially be stronger than those observed in this study; treatment plots were surrounded by thick stands of *E. lehmanniana*, providing ample seed source and the opportunity for the plant to vegetatively encroach.

Following removal of *E. lehmanniana*, substantial increases in the cover of annual species, forb species, and native species were observed. These increases are not attributable to the increase in one or two species, but rather to broader shifts in community composition. Species demonstrating the greatest increases on treated plots were *Mollugo verticillata*, *Nissolia wislizeni*, *Evolvulus nuttallianus* J.A. Schultes, and *Calliandra eriophylla* (Table 5). *Calliandra eriophylla* is a native perennial shrub. Both *Nissolia wislizeni* and *Evolvulus nuttallianus* are native perennial forb species. Similarly, other community-level studies have demonstrated an increase in less common species following removal of the dominant species (Hils and Vankat 1982, Silander and Antonovics 1982, Farnsworth and Meyerson 1999).

Above-ground glyphosate application had some effects on the seed bank following the treatment. On a community basis, seed bank samples from glyphosate-treated plots were significantly different from control plots once in the second year of the

study (Table 9). These differences were in part due to the smaller numbers of *E. lehmanniana* seeds germinating in samples from treated plots at these sites and also because of the presence of other species, typically native species. This demonstrates the potential for a strong response on behalf of native species residing in the seed bank to the removal of *E. lehmanniana* on these sites.

Treatment effect - Sethoxydim

No treatment effects were evident on plots treated with sethoxydim (Vantage) herbicide. Little research has been published on the efficacy of sethoxydim on *E. lehmanniana.* Rice (1992) and Zandstra et al. (2004) listed sethoxydim as one of several herbicides to use on lovegrasses, but does not specify the species on which sethoxydim is effective. *Eragrostis cilianensis* is listed as a target species on the Sethoxydim G-Pro Herbicide label, but *E. cilianensis* is a summer annual grass, sharing only some morphological characteristics with *E. lehmanniana.* The lack of treatment effect may be due to the short duration of this portion of the study; repeated applications of sethoxydim may be required for *E. lehmanniana* to be impacted.

Climate and soil influences on the effects of removal

Seasonal rainfall did not vary substantially over the three years of the study (Table 10). There does not seem to be obvious patterns between recorded rainfall and patterns observed in the treatment plots. However, the timing and intensity of the precipitation may explain some of the variations in community composition observed in the ANOSIM tests across seasons (Table 5). Additionally, responses to future herbicide treatments at this site may be very different from those observed in this study if rainfall is very high or very low. Recent greenhouse and field studies have demonstrated the sensitivity of native species to variable rainfall patterns (Frasier et al. 1985, Frasier 1989, Abbott et al. 1995, Abbott and Roundy 2003). High and rapid germination rates of native species are common following initial rainfall events. However, without consistent rainfall following germination, these species are susceptible to desiccation (Abbott and Roundy 2003).

Correspondence between plant communities and seed banks

The most common species germinating in the seed bank but not appearing in aboveground vegetation was *Pseudognaphalium arizonicum. Oxalis corniculata, Sisymbrium irio,* and *Veronica peregrina* L. were also common. All of these are native annual forbs, with the exception of *Sisymbrium irio,* which is not native to the continent. The most abundant species in the seed bank that also appeared in the aboveground vegetation included *Muhlenbergia* The lack of perennial grass species is not surprising, but the presence of native annual species is heartening.

Inconsistencies between aboveground vegetation and seed banks are often observed (Thompson and Grime 1979, Rabinowitz 1981, Hills and Morris 1992, Warr et al. 1993, Arkle et al. 2002). It has been suggested that species observed in seed banks but

not expressed in aboveground vegetation are a "memory" of past ecological conditions at the site and may germinate if these conditions reappear (Templeton and Levin 1979, Rabinowitz 1981). Another viable explanation for seed bank species not appearing in aboveground vegetation is lack of necessary soil moisture in the field, which is one of the most important site characteristics for germination (Winkel et al. 1991). Regardless, these species offer insight into the possible trajectory of the site following a large-scale removal of *E. lehmanniana*. The results of the *E. lehmanniana* removal experiment and the seed bank study suggest that upon removal of *E. lehmanniana*, the native species latent in the seed bank begin to appear in aboveground vegetation. *E. lehmanniana* also continues to reappear from seed as expected due to its high degree of dormancy (Weaver and Jordan 1986, Voigt et al. 1996). However, the numbers of *E. lehmanniana* are reduced considerably when the aboveground *E. lehmanniana* seed inputs are removed.

Native species observed in both seed banks and aboveground vegetation were in large part annual species. Removing *E. lehmanniana* from a site heavily dominated by this species resulted in the removal of nearly all plant cover on treatment plots. The proliferation of annual species following this disturbance could be the natural response of plants in this area. It may be possible to expect change to continue on sites if *E. lehmanniana* were to continue to be excluded from treatment plots, and result in the eventual establishment of native perennial species. Further studies are necessary to determine whether such a pattern would occur.

Potential for site restoration

Some observations made over the course of this study suggest there is potential for restoring this site to a community less dominated by *E. lehmanniana*. Repeated application of glyphosate (RoundUp) herbicide to *E. lehmanniana* did have a significant impact on *E. lehmanniana* cover. Nearly all species occupying the plots following treatment were native species. However, follow-up application of herbicide was required several times over the course of the study, as new *E. lehmanniana* individuals germinated continually from the seed bank. Seed bank trials revealed differences in the species richness and composition of samples only in the final season tested, suggesting a possible shift in seed bank with continual above-ground *E. lehmanniana* removal.

A large-scale *E. lehmanniana* eradication effort at Coronado NM would require a large time and monetary commitment. Approximately 400 ha are heavily infested by *E. lehmanniana* at this site. A single treatment would cost approximately $800 USD in glyphosate herbicide. Broadcast treatment using farm equipment would be easiest, but may not be feasible given the complex topography and access issues for the site. Additionally, broadcast treatment would result in overspray reaching non-target species, unless great precautions were taken. Treatment by hand would be much more costly and time-consuming. Based on the time taken to treat plots in this study, it is estimated that an initial herbicide treatment by hand to cover all infested area on the Monument would take over 22,000 person-hours, an entirely infeasible amount of time. Repeat applications in successive seasons would be necessary to target newly germinating plants. Therefore, this pre-eradication assessment has demonstrated that control of *E. lehmanniana* could be

possible, but is not feasible or cost-effective at this site unless mechanized equipment could be implemented.

If a large-scale *E. lehmanniana* control effort were desired, it may be advisable to undertake restoration measures in conjunction with removal efforts. Seeds of native perennial species may promote transition from an annual-dominated site to a more diverse, perennial-dominated community.

Management Recommendations

For small-scale control efforts, glyphosate (RoundUp) herbicide is an effective control for *E. lehmanniana*. Several, if not many, follow-up treatments are required to control the reappearance and spread of this aggressive grass. *E. lehmanniana* produces copious wind-borne seeds; additionally, seeds remain germinable in the soil for an unknown length of time. The vigilance required to prevent this species from reestablishing following a removal treatment should be considered when restoration efforts are being planned. Additionally, the caution required to avoid spraying non-target plants during treatment should also be carefully considered.

Based on the findings of this study, the selective herbicide, sethoxydim (Vantage), does not seem to be an effective herbicide treatment for the control of *E. lehmanniana*. The selective herbicide imazapic (Plateau) has been recommended for the control of *E. lehmanniana* (USDOI 2004); further testing of this grass-specific chemical at Coronado NM should be pursued.

Conclusions

Although the negative impacts of introduced species are widely recognized (Chapin et al. 1996, Mack and D'Antonio 1998, Wilcove et al. 1998), few studies are undertaken to examine the response of a site following a large-scale eradication effort. Eradication or control is often the preferred response to an invasion by a particularly problematic species, but as Zavaleta et al. (2001) propose, pre-eradication assessments are necessary to determine whether a removal will result as expected and not augment the problem. The results of this study suggest that the response to the removal of *E. lehmanniana* using glyphosate was positive, but the response using sethoxydim was negligable. Removal using glyphosate yielded large increases in native plant cover, increases in species richness and no evidence of "new" nonnative species replacing removed species. This finding is consistent with other experiments removing dominant nonnative species (Farnsworth and Meyerson 1999, Morrison 2002).

Seed bank studies revealed a small number of additional species not observed in the aboveground vegetation. This pattern suggests that removing *E. lehmanniana* would result in the site's conversion to an ecosystem dominated by native plants. However, it may be advisable to undertake restoration measures in conjunction with removal efforts. Seeds of native perennial species may promote transition from an annual-dominated site to a more diverse, perennial-dominated community.

Several studies have suggested that the responses observed following a species removal could be the result of indirect effects including the concurrent soil disturbance, breakdown of aboveground or root biomass, and transient responses in nutrient availability (Underwood 1986, Aarssen and Epp 1990, Campbell et al. 1991). The short time span of this study (less than three years post-treatment) precludes determination of the importance of these effects. Removal of competition for resources including space, light, or nutrients could also be responsible for the response. Further monitoring of the study plots would demonstrate the site's long-term response to the removal.

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Appendix A

Study Photographs



Study site at Coronado National Memorial prior to initiation of the study, dominated by *Eragrostis lehmanniana* (Lehmann lovegrass). Photo 10/02.



Herbicide application to glyphosate-treated plots. Photo 5/14/03.



Glyphosate-treated plot in first fall following treatment. Photo 8/1/03.



Glyphosate-treated plot in second fall following treatment. Photo 9/1/04.



Glyphosate-treated plot in third fall following treatment. Photo 9/12/05.



Glyphosate-treated plot in third fall following treatment. Photo 9/12/05.



Sethoxydim-treated plot one season following treatment. Photo 9/12/05.



Greenhouse set-up for seed bank study. Photo 4/15/04.

Appendix B

Financial Accounting

FY2004

Salary	
1 pay period, GS-9 SCEP Ecologist	$1,941
Equipment (herbicide, rebar, training for herbicide application, tapes, greenhouse supplies)	$810
Equipment purchased by CORO	$340
Cooperative Agreement with University of Arizona (undergraduate student greenhouse assistance; greenhouse fees)	$3,643
Cooperative Agreement with Sonoran Institute (graduate student assistance with data entry, field assistance, data management, plant identification)	$13,266

FY2005

Cooperative Agreement with Sonoran Institute (graduate student assistance with data entry, field assistance, data management, plant identification)	$20,000

SODN In-kind Project Costs (FY2004 and 2005)

GS-9 SCEP Ecologist: 20 days x 8 h x $22/hr	$3,520
Others' field time:	
Jason: 2 days x 8 h x $13/hr	$208
Melissa: 10 days x 8 h x $12/hr	$960
Kristen: 4 days x 8 h x $12/hr	$384
Meg: 5 days x 8 h x $18/hr	$720
Jeff M.: 3 days x 8 h x $15/hr	$360
Jeff B.: 2 days x 8 h x $13/hr	$208
Sarah: 2 days x 8 h x $13/hr	$208
Volunteer time (in-kind): 20 days x 8 h = 160 hours	
My time in greenhouse: 6h/wk x 104 weeks x $22/hr	$13,728
Data management, analysis, reporting:	
Data entry: 5 days x 8 h x $12/hr	$480
Analysis & reporting: 25 days x 8 h x $22/hr	$5,000
Vehicle use: 20 trips x 100 miles x .32/mile	$640
Equipment:	
Soils testing	$200
TOTAL	**$26,616**