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13. ABSTRACT *(Maximum 200 Words)*

Because increased abundance of nonnative lovegrasses likely is detrimental to some native species and to overall biological diversity in the southwestern United States, we initiated an experimental assessment of the influence of fire regime on abundance of nonnative lovegrasses and biological diversity. Our specific objectives are to (1) determine effects of fire season on responses of biotic communities, and (2) quantify relationships between biological guilds before and after burning and through post-fire recovery. This experiment is taking place within grasslands and *Prosopis* savannas at the Fort Huachuca Military Reservation (FHMR) (three replicates in each of two years). Pre-treatment sampling indicated an inverse relationship between biomass of the dominant nonnative grass (*Eragrostis lehmanniana*) and diversity and richness of native species. Experimental fires were applied in spring and summer of 2001 and 2002. Post-treatment sampling indicates that *Eragrostis lehmanniana* increased following spring fires but not following summer fires or no fires. Plant species richness followed a similar pattern, with decreased richness attributed to spring fires. Plant species diversity dropped sharply in all plots at the end of a severe drought, and recovered similarly regardless of fire season.

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Fire-based restoration of biodiversity in ecosystems dominated by nonnative grasses

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Introduction

As nonnative species continue to increase in distribution and abundance, so do their interactions and effects on indigenous species. Increases in some nonnative species have reduced or eliminated indigenous plants and animals, and thereby contributed to changes in species diversity and community composition (e.g., Bock et al. 1986, OTA 1993). These types of changes have consequential implications for ecosystem function (Naeem et al. 1996).

In the southwestern United States, establishment and spread of nonnative Lehmann lovegrass (*Eragrostis lehmanniana* Nees) and Boer lovegrass (*Eragrostis chloromelas* Steud.) appear to be disrupting native ecosystem processes at multiple spatial and temporal scales. Prescribed fire has been proposed as a restoration tool in these semi-arid systems, even though considerable evidence suggests that fires enhance establishment of these nonnative lovegrasses (e.g., Cable 1965, 1971, Ruyle et al. 1988, Sumrall et al. 1991, Robinett 1992, Biedenbender and Roundy 1996). Because increased abundance of nonnative lovegrasses likely is detrimental to some native species and to overall biological diversity, we have initiated an experimental assessment of the influence of fire regime on abundance of nonnative lovegrasses and biological diversity. Our specific objectives are to (1) determine effects of fire season on responses of biotic communities, and (2) quantify relationships between biological guilds before and after burning and for several years post-fire.

Body

Study sites

Our experiment is taking place primarily within grasslands and *Prosopis* savannas at the Fort Huachuca Military Reservation (FHMR) (31° 34′ N, 110° 26′ W) in the Huachuca

Mountains of southern Arizona. Elevations range from 1420 to 1645 meters and about 66% of average annual precipitation of 440 mm falls between July-October and 20% falls between December-March (NOAA 1992). A hot, dry period between late March and early July prior to the onset of monsoons characterizes this region. Some areas on FHMR have not burned between 1977 and 2002 whereas other areas have burned as frequently as every 3 years. Few livestock grazed FHMR since the late 1800s, and livestock have been excluded since 1950.

Additional replicates of our bird study plots are located at the Buenos Aires National Wildlife Refuge, approximately 150 km west of FHMR. Elevation of these plots is 1100 m and annual precipitation is similarly bimodal, averaging 300 mm annually in the area of our study plots (Kirkpatrick et al. 2002). Burn history is similar to that of FHMR, and cattle have been excluded at Buenos Aires since 1985.

Experimental Design

We have developed and initiated a split-plot experimental design with a full-factorial treatment structure. The extant plant community is the whole-plot factor (levels: native-grass dominated, introduced-lovegrass dominated, and mixed native and lovegrass, described below) and burn season is the treatment (spring fire, summer fire, no fire). Plots are 1 ha, which is large enough to minimize edge effects and to allow adequate sampling of the plant, invertebrate, and small mammal communities. Bird study plots are 9 ha, and are placed on top of or adjacent to 1-ha plots. This larger size is more appropriate to the scale of breeding bird movements, yet allows us to maintain the whole-plot factor. Burn treatments on 9-ha plots include only summer fire in 2001 and no fire.

Plot Selection and Allocation

We identified 3 types of grasslands, representing a continuum of invasion by nonnative species:

- Grasslands dominated by the nonnative grass *Eragrostis lehmanniana*
- Native-dominated grasslands with *Aristida* spp., *Bothriochloa barbinodis*, *Bouteloua* spp., *Digitaria californica*, *Eragrostis intermedia*, and *Panicum* spp.
- Grasslands composed of a mix of nonnative and native species.

In the summer of 1999, we chose 18 sets of 3, 1-ha plots at FHMR, 6 within each of these 3 types of grassland community. Each of the 3 plots within a set received 1 of the 3 fire treatments, and we treated plots in 9 of 18 sites in each of the 2 years, 2001 and 2002. We used a total of 3 replicates per community type (n = 3) per treatment (n = 3) in a given year (n = 2). We marked the corners of all plots with metal fence posts and recorded coordinates using a global positioning system (GPS) to ensure the plots could be relocated.

In spring 2000, we located 15 circular plots (170-m radius; 9 ha) in each of the 3 grassland types at FHMR (n = 45), and 9 plots in each of the 3 types at Buenos Aires (n = 9). Each FHMR plot received 1 of 2 fire treatments (spring fire or no fire); Buenos Aires plots were not treated. At FHMR we used 3 replicates per community type (n = 3) per treatment in 2001. We marked the center of all plots with a metal fence post, and recorded coordinates with a GPS.

Vegetation Sampling

We measured plant biomass in 25, 1 m x 0.5 m quadrats in 27 plots (at 9 sites) in autumn 1999 and spring 2000 and in 54 plots (at 18 sites) in autumn 2000, spring 2001, autumn 2001, spring 2002, and autumn 2002. Vegetation was clipped 2.5 cm above the ground and separated into species. Samples were oven-dried to constant weight at 65 °C. We summarized the data for species richness (average number of species per plot) and Simpson's index of diversity (average number of species and their relative abundance).

Although there was considerable temporal variation, plant species richness was consistently highest in plots with no nonnative grasses, intermediate in those with moderate levels of nonnative grasses, and lowest in those dominated by nonnative grasses (Fig. 1). Species richness peaked in spring 2001 likely due to a response by annual forbs to an abundance of winter rainfall. Interestingly, richness fell sharply in fall 2001 perhaps in response to lower than normal rainfall during the summer monsoons of 2001. Accordingly, as biomass of the dominant nonnative grass, *E. lehmanniana*, increased, plant diversity declined markedly (Fig. 2).

Native plant communities show little response to fire treatment whereas mixed and nonnative communities show a slight decline in species richness in response to spring fires (Fig. 3). We predict that the decline in richness is related to the rapid increase in abundance of *Eragrostis lehmanniana* following spring fires.

Small Mammal Sampling

We trapped small mammals and invertebrates in 27 plots (9 sites) in spring and summer 2000 and 54 plots (18 sites) in winter, spring, and summer 2001 and 2002 (see Table 1 for species lists). We sampled small mammals using an 8×8 grid of folding Sherman traps (12-inch, ventilated) at 15-m spacing (64 traps per plot) for 5 days. We marked captured animals with ear tags and secondary color markings.

Species richness of small mammals was relatively consistent over time, with the exception of slightly higher values in nonnative grass and mixed grass communities in both the winter and spring of 2002 (Fig. 5). Relative abundance of small mammals varied considerably over time, peaking in summer 2000 for all vegetation communities, and again in winter and spring 2002, but only in mixed grass and nonnative grass-dominated communities, where species richness also increased. Within a given season, however, relative abundance was similar across the gradient of nonnative-grass invasion (Fig. 6).

There was no apparent effect of prescribed fire on species richness of small mammals (Fig. 7), as values overlapped with that of unburned controls. However, some species responded strongly immediately following fire, including *Baiomys taylori*, which was rarely captured in plots immediately after fire (i.e., only a single individual was captured on a native grass-dominated plot following a summer fire), and all three species of *Sigmodon* (*S. arizonae*, *S. fulviventer*, and *S. ochragnathus*) which were rarely captured immediately after fire, and only in plots dominated by nonnative grasses following summer fire. All of these species were commonly captured on unburned control plots, especially *S. arizonae*. There was also some indication of a decrease in the relative abundance immediately following both spring and summer fires in 2002 (Fig. 8), in all vegetation communities, possibly as a result of drier conditions at the time of these fires, as compared to 2001, when no immediate effect of fire was detected.

Invertebrate Sampling

We sampled invertebrates using pitfall traps in a 3×3 grid in each plot for 24 hours concomitant with small mammal trapping periods. We have been accumulating a reference collection since the initiation of this project, consisting of over 1000 taxa, which we are in the process of identifying. Approximately one-third of all specimens in the collection have been identified to order and family. We will begin data analysis after identification is complete.

Bird Sampling

Between April and September in 2000, 2001, and 2003 we counted birds seen and heard in 9-ha plots at FHMR and Buenos Aires, visiting each plot 8-9 times. Species richness of birds on unburned plots (mean ± SE) was similar across the vegetation gradient (4.3 ± 0.10 to 4.4 ± 0.11), as was relative abundance (6.9 ± 0.17 to 7.3 ± 0.19). We also found no difference one year post-fire at FHMR in abundance on burned ($F_{2,6}$ 0.89, P = 0.46) or unburned ($F_{2,21}$ 1.62, P = 0.22) plots (Fig. 9), or in species richness on burned ($F_{2,6}$ 1.36, P = 0.36) or unburned ($F_{2,21}$ 1.65, P = 0.22) plots (Fig. 10). In native and mixed vegetation plots we observed a difference between burned and unburned areas in both richness (t_{19} = 3.67, P = 0.002) and abundance (t_{19} = 4.67, P <0.001), but not in lovegrass dominated grasslands (P >0.60 for each measure).

When considering collections of similar species (guilds), some additional patterns are evident. In unburned plots at both Buenos Aires and FHMR in 2001-2003, we consistently found fewer ground-nesting ($F_{2,51}$ 7.85, P = 0.001) and ground-foraging birds ($F_{2,51}$, 8.31, P <0.001) in native grasslands (Fig. 11). On FHMR plots in 2001, we found evidence of a positive relationship between relative abundance of ground foraging birds and lovegrass dominance in unburned ($F_{2,21}$ 4.44, P = 0.025), and to a lesser extent burned ($F_{2,6}$ 2.85, P = 0.135) grasslands

(Fig. 12). Relative abundance of ground-nesting birds was similarly distributed, generally increasing with lovegrass dominance in unburned ($F_{2,21}$ 3.61, P = 0.045) but less clear in burned ($F_{2,6}$ 1.29, P = 0.342) grasslands.

We also searched for and monitored the fate of bird nests in both 2000 and 2001. Nests were found by rope dragging and through observations of adult bird behavior. A total of 138 nests were found in 2000 and 224 in 2001. Most commonly found nests were those of mourning doves and Botteri's sparrows. Although we have not yet examined the influence of fire on nest associations, it is apparent that vegetation composition played a role in nest-site location. Although we found no clear difference in density of nests (number of nests/9 ha, mean ± SE) in the full avian community across the gradient of lovegrass dominance (4.2 ± 0.74 to 7.2 ± 1.13; $F_{2,42}$ 2.11, P = 0.134), we did find a general pattern at a different scale of resolution. Of ground-nesting species that nest in clumps of vegetation (n = 54 nests on all plots combined), these birds more often built in clumps of native grasses (62.9%) than clumps of Lehmann lovegrass (24.1%) or other vegetation (12.9%).

Key Research Accomplishments

Pre-treatment sampling indicates:

- A slight negative relationship between biomass of *Eragrostis lehmanniana* and diversity and richness of native species. There is no clear relationship between frequency (number of quadrats containing *E. lehmannniana*) and species richness. Moreover, some plots have relatively low richness despite little or no presence of *E. lehmanniana*.

- Species richness and relative abundance of small mammals were similar across the gradient of nonnative-grass invasion. Temporal variability observed is likely due, in part, to variation in rainfall patterns and resulting changes in the vegetation community.
- Breeding bird species richness and relative abundance within the avian community were similar across the gradient of nonnative-grass invasion, but abundance of ground-dwelling (ground nesting and ground foraging) birds was lowest in native-dominated grasslands. Nest density was relatively consistent along the nonnative-grass gradient, but ground-nesting birds placed nests more often in native grasses than in exotic grasses or other vegetation.

Post-treatment sampling indicates:

- Dominance of the nonnative grass *Eragrostis lehmanniana* and plant community richness are related to fire season and to precipitation patterns preceding and following prescribed fires.
- Species richness of small mammals, in the short term, was relatively unaffected by fire, in either season, although some species-specific responses were apparent. There was some indication of a decrease in relative abundance of small mammals, regardless of vegetation community, immediately following prescribed fires in 2002.
- Although patterns of species richness and relative abundance in the breeding bird community remained unaffected within each treatment group across the nonnative-grass gradient, spring burning increased richness and abundance in both native dominated and mixed composition grasslands in one year post-fire. Further, spring

burning disrupted an apparent positive relationship between abundance of ground-dwelling birds and lovegrass dominance.

Reportable Outcomes

Manuscripts and presentations

We have collected an extensive pre-treatment dataset, which has served as the basis for several invited presentations about this experiment. Specifically, we delivered three presentations at the Malpai Borderlands Group annual science symposium in Douglas, Arizona in January 2001 (Fire in southwestern grasslands; An experimental approach to assess the effects of fire in southwestern grasslands; Future research needs determined by changes in semi-desert grassland plant communities 10 years after cessation of grazing and reintroduction of fire), one presentation to the Fort Huachuca Conservation Committee in May 2001 (Fire effects in southwestern grassland: an experimental approach at Fort Huachuca), two presentations at the annual meeting of the Arizona/New Mexico Chapters of The Wildlife Society in Safford, Arizona, in February 2002 (Effects of nonnative grasses on small mammal populations and communities, Responses of grassland bird communities to invasion by nonnative grass), one presentation at the annual conference for Research and Resource Management in Southwestern Deserts in May of 2002 (Avian response to Lehmann lovegrass in southeast Arizona grasslands), one presentation for the Sonoita Valley Planning Partnership in July 2002 in Sonoita, Arizona, two presentations at the annual Ecological Society of America meetings in Tucson, Arizona in August 2002 (Razing Arizona: fire and nonnative grass in semi-desert grasslands, Effects of nonnative grasses on small mammal populations and communities), and one presentation at the annual meeting of The Wildlife Society in September 2002, in Bismarck, North Dakota (Responses of grassland bird communities to invasion by nonnative grass). Additional presentations and several manuscripts will be developed following collection of additional post-treatment data.

Employment and Educational Opportunities

This project has supported 46 seasonal employees and three graduate research assistants. It forms the basis for the research-based education each of the three graduate students, as well as providing educational opportunities and employment for 2 undergraduate researchers.

Conclusions

These preliminary data form the basis for a rigorous, long-term, experimental study of vegetation, small mammals, birds, and invertebrates within the context of invasion by a widespread nonnative plant. This experiment is the first major experimental study of fire and nonnative plants, and it incorporates responses of all major taxa.

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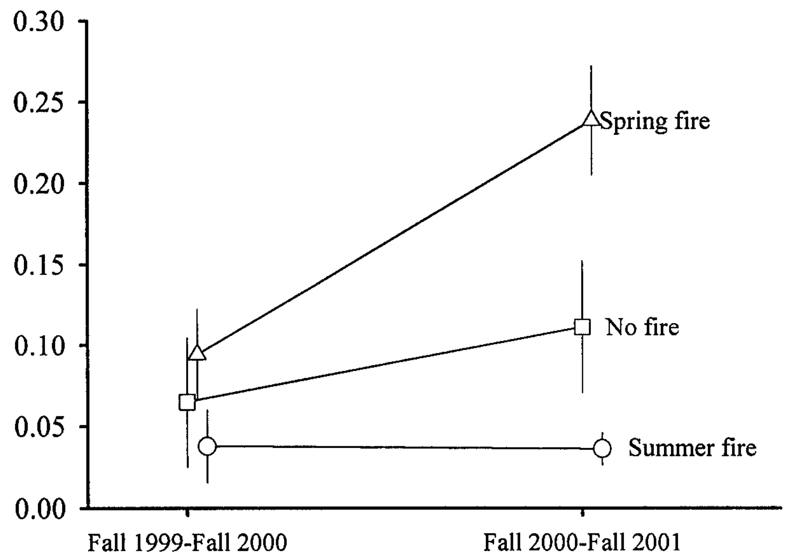

Figure 1. Change in the proportion of Eragrostis lehmanniana in nonnative-dominated community types after spring, summer, and no fire in semidesert grasslands at Fort Huachuca Military Reservation, Arizona.

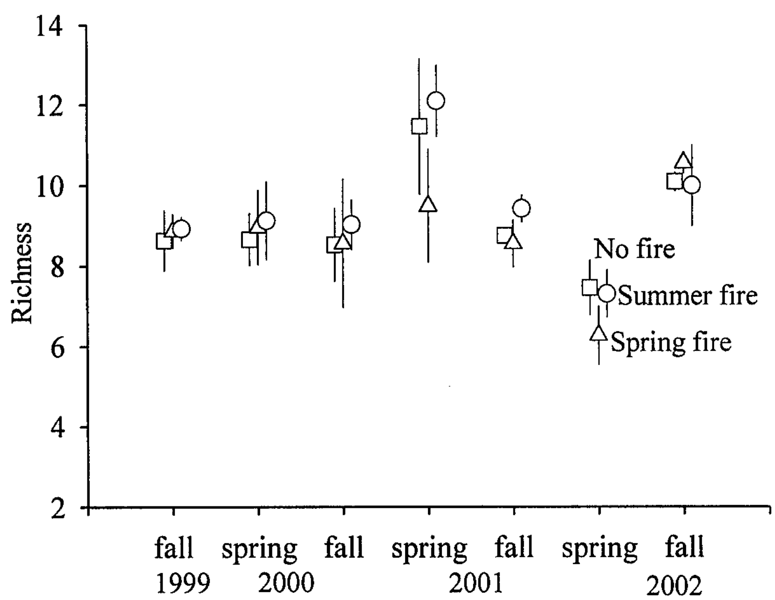

Figure 2. Changes in richness over six sampling periods in native-dominated communities following fire treatment in semidesert grasslands at Fort Huachuca Military Reservation, Arizona

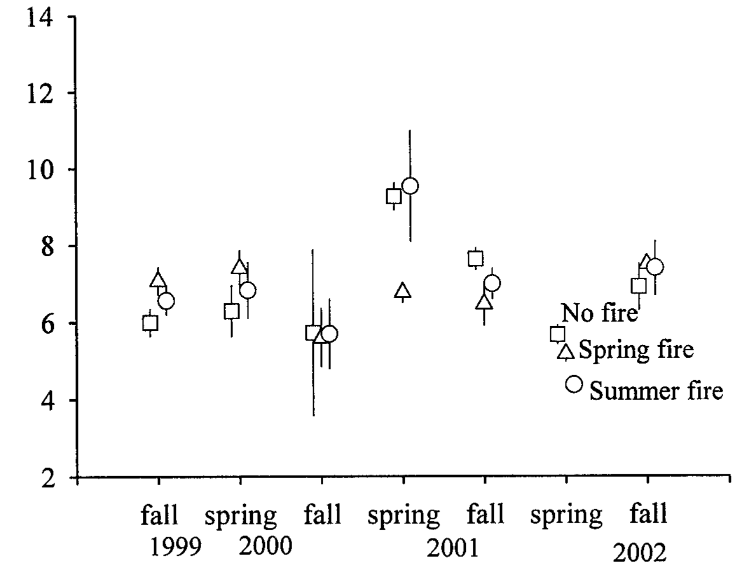

Figure 3. Changes in richness over six sampling periods in mixed communities following fire treatment in semidesert grasslands at Fort Huachuca Military Reservation, Arizona.

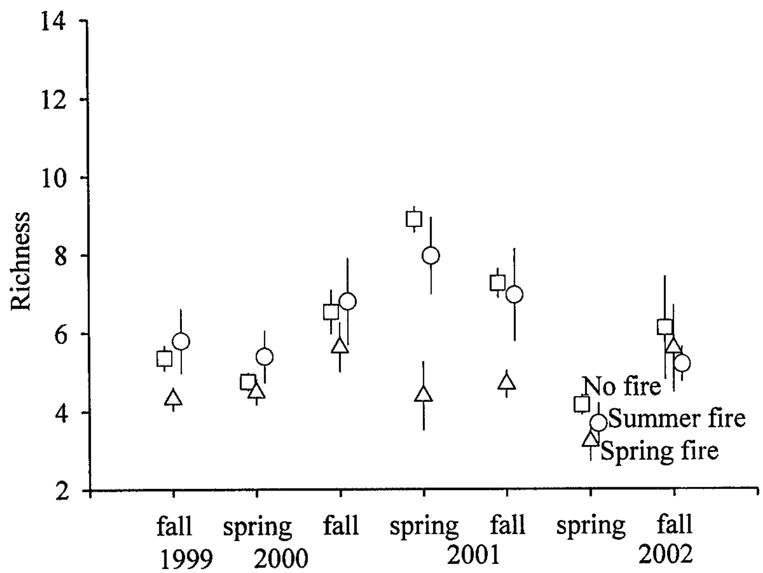

Figure 4. Changes in richness over six sampling periods in nonnative-dominated communities after fire treatment in semidesert grasslands at Fort Huachuca Military Reservation, Arizona.

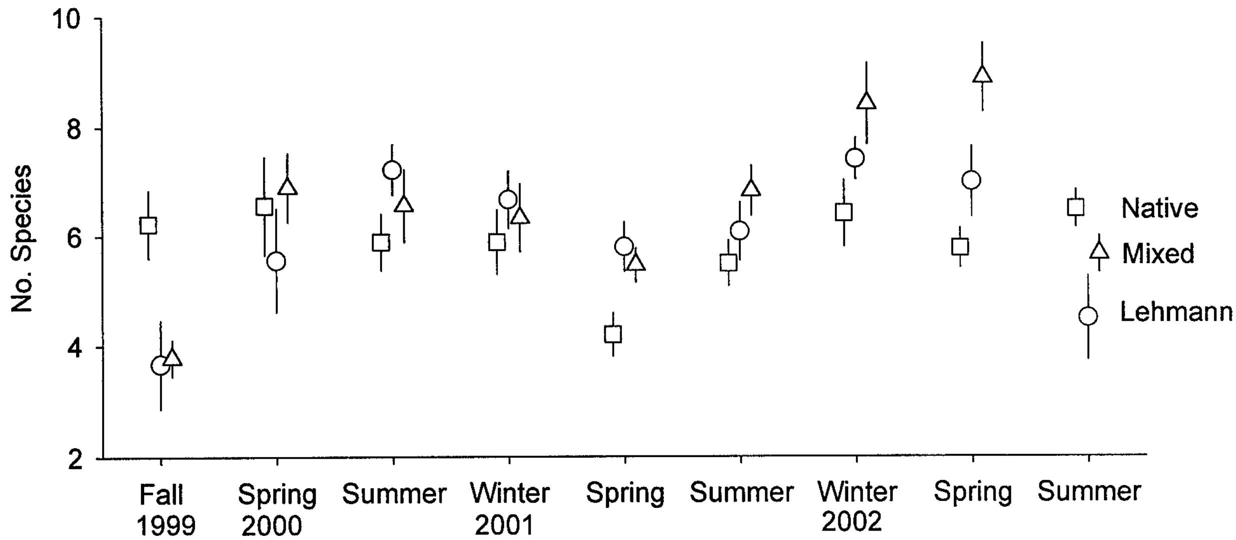

Fig. 5. Species richness of small mammals captured over time across the gradient of invasion by the nonnative grass. Symbols represent means and error bars are 1 standard error.

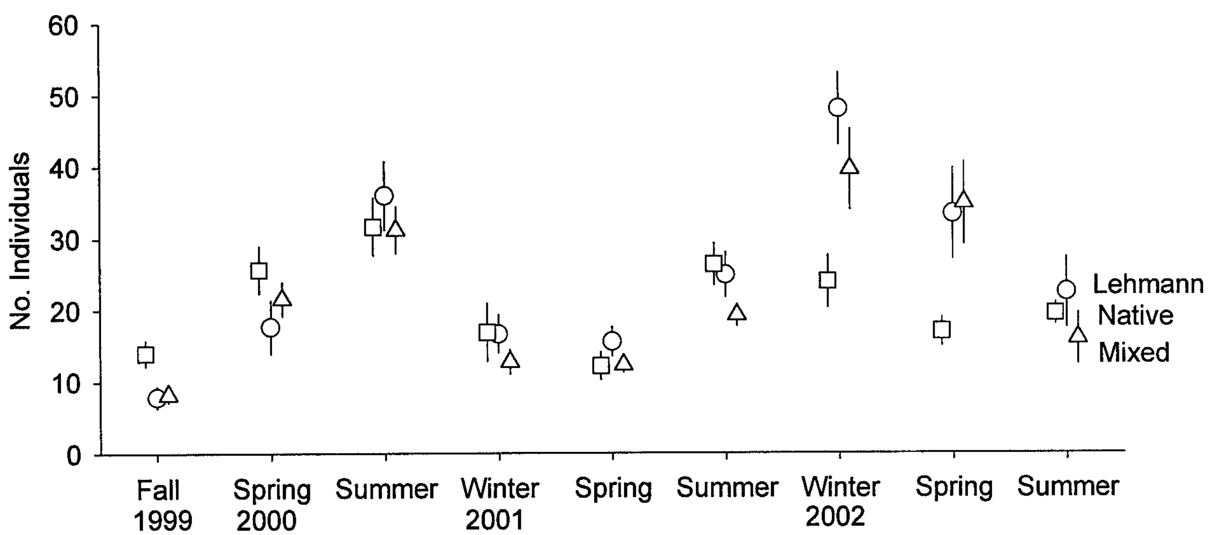

Fig. 6. Relative abundance of small mammals captured over time across the gradient of invasion by the nonnative grass. Symbols represent means and error bars are 1 standard error.

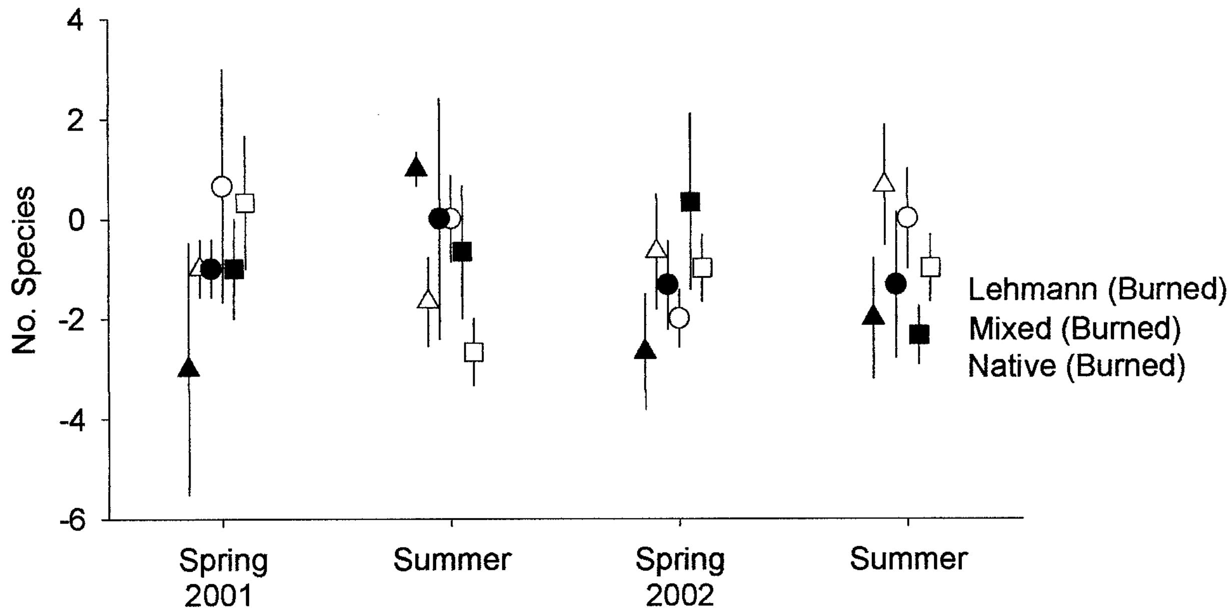

Fig. 7. Difference between species richness of small mammals captured immediately before and immediately after fire (black symbols) compared to corresponding unburned control plots (white symbols). Symbols represent the mean value and error bars are 1 standard error.

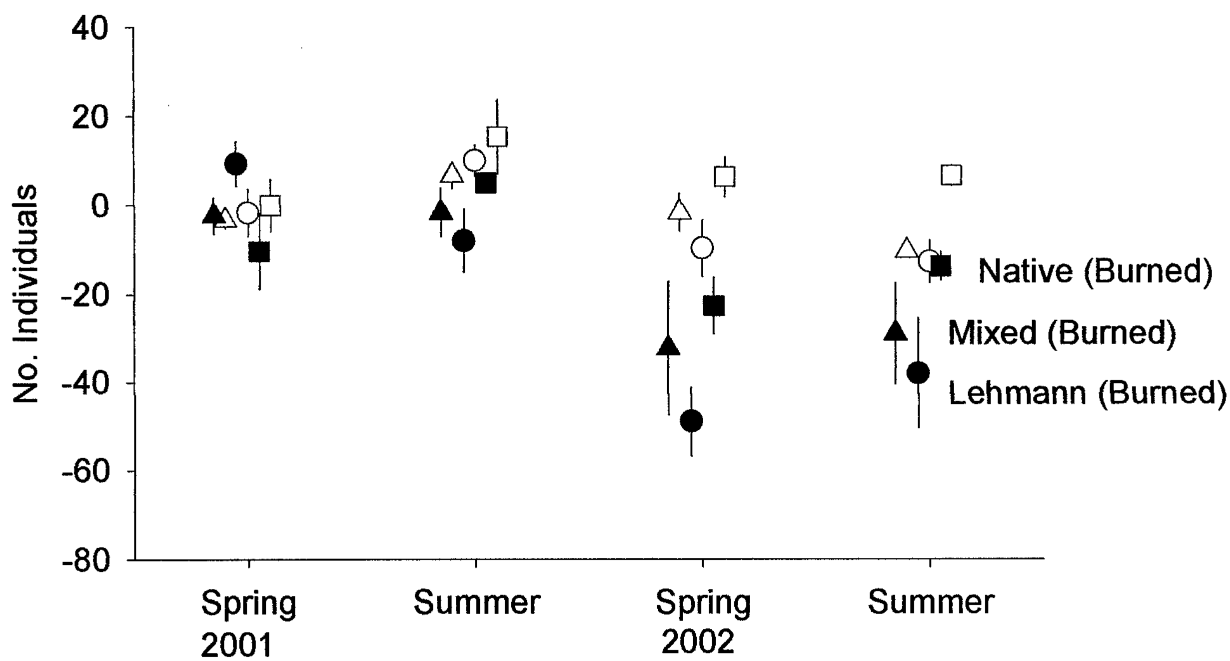

Fig. 8. Difference between relative abundance of small mammals captured immediately before and immediately after fire (black symbols) compared to corresponding unburned control plots (white symbols). Symbols represent the mean value and error bars are 1 standard error.

Figure 9. Relative abundance of birds in burned and control 9 ha plots along the gradient of lovegrass dominance, Fort Huachuca Military Reservation and Buenos Aires NWR, Arizona, 2000-2003.

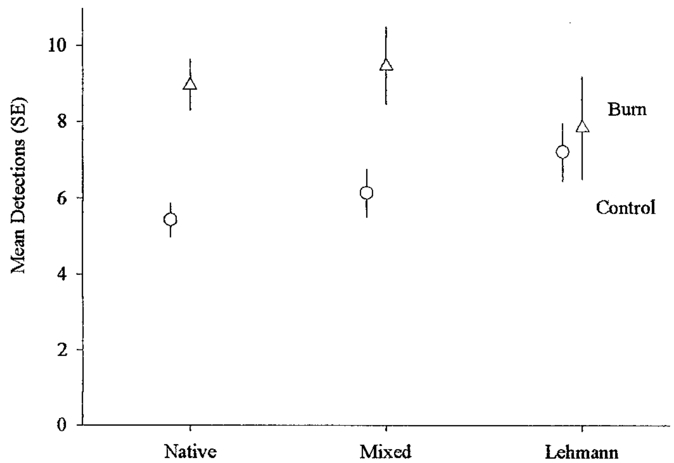

Figure 10. Mean species richness of birds in burned and control 9 ha plots along the gradient of lovegrass dominance, Fort Huachuca Military Reservation, Arizona, 2001.

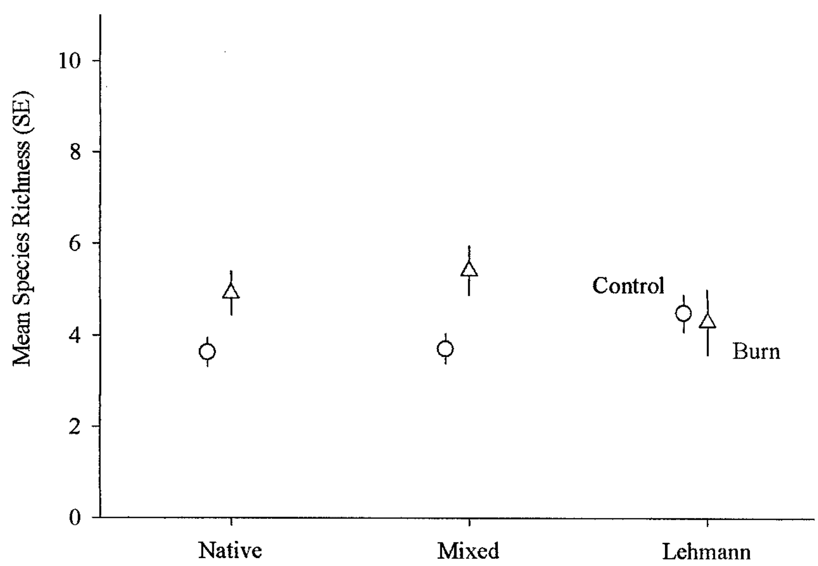

Figure 11. Mean percentage of total number of detections representing ground foragers and ground nesters along the gradient of lovegrass dominance. Fort Huachuca Military Reservation and Buenos Aires, AZ, 2000-2003.

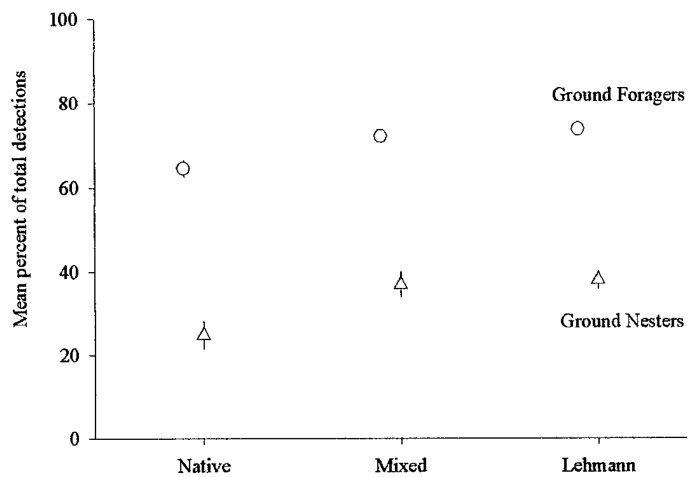

Figure 12. Mean percentage of total number of detections representing ground foragers and ground nesters on burned and control 9 ha plots along the gradient of lovegrass dominance. Fort Huachuca Military Reservation, Arizona, 2001.

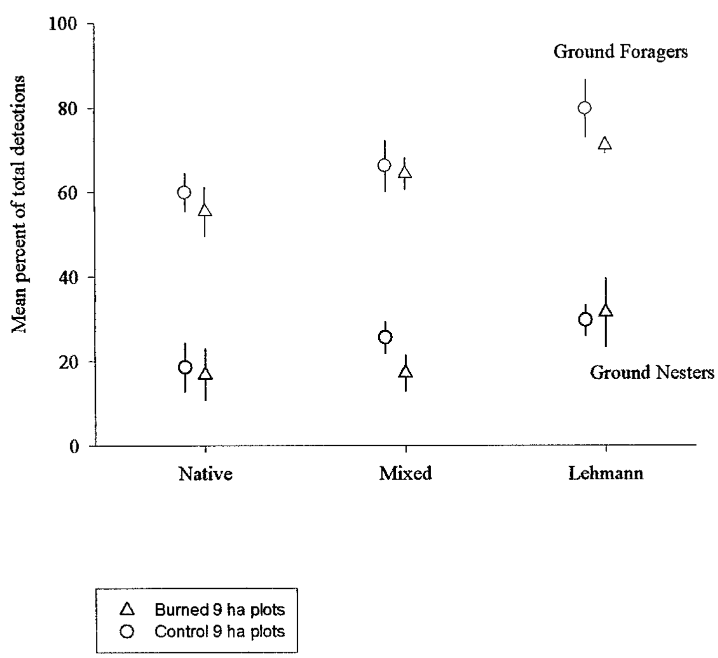

Table 1. Small mammal species captured during the 2000 and 2001 trapping periods at Fort Huachuca Military Reservation.

Species name	**Common name**	**Spring 2000**	**Summer 2000**	**Winter 2001**	**Spring 2001**	**Summer 2001**	**Winter 2002**	**Spring 2002**	**Summer 2002**
Baiomys taylori	Northern pygmy mouse	X	X	X	X	X	X	X	X
Chaetodipus baileyi	Bailey's pocket mouse		X			X		X	X
Chaetodipus intermedius	Rock pocket mouse	X	X		X	X	X	X	
Chaetodipus penicillatus	Desert pocket mouse	X	X	X	X	X	X	X	X
Dipodomys merriami	Merriam's kangaroo rat	X	X	X	X	X	X	X	X
Dipodomys ordii	Ord's kangaroo rat			X				X	X
Neotoma albigula	White-throated wood rat	X	X	X	X	X	X	X	X
Onychomys leucogaster	Northern grasshopper mouse	X	X	X	X	X	X	X	X
Onychomys torridus	Southern grasshopper mouse	X	X	X	X	X	X	X	X
Perognathus flavus	Silky pocket mouse	X	X	X	X	X	X	X	X
Perognathus hispidus	Hispid pocket mouse	X	X	X	X	X		X	X
Peromyscus boylii	Brush mouse	X						X	X
Peromyscus eremicus	Cactus mouse	X	X	X			X	X	X
Peromyscus leucopus	White-footed mouse	X		X	X	X	X	X	X
Peromyscus maniculatus	Deer mouse	X	X	X	X	X	X	X	X
Reithrodontomys fulvescens	Fulvous harvest mouse	X	X	X	X	X	X	X	X
Reithrodontomys megalotis	Western harvest mouse	X	X	X	X	X	X	X	X
Reithrodontomys montanus	Plains harvest mouse	X	X	X	X	X	X	X	X
Sigmodon arizonae	Arizona cotton rat	X	X	X	X	X	X	X	X
Sigmodon fulviventer	Fulvous cotton rat	X	X	X	X	X	X	X	X
Sigmodon ochrognathus	Yellow-nosed cotton rat	X	X	X	X	X	X	X	X
Spermophilus spilosoma	Spotted ground squirrel	X	X		X	X		X	X
	TOTAL SPECIES	**20**	**19**	**18**	**18**	**19**	**17**	**22**	**21**