

No Positive Feedback Between Fire and a Nonnative Perennial Grass

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Abstract—Semi-desert grasslands flank the “Sky Island” mountains in southern Arizona and Northern Mexico. Many of these grasslands are dominated by nonnative grasses, which potentially alter native biotic communities. One specific concern is the potential for a predicted feedback between nonnative grasses and fire. In a large-scale experiment in southern Arizona we investigated the interaction between fire season and Lehmann lovegrass, a perennial bunchgrass from Southern Africa. We observed a slightly increasing proportion of Lehmann lovegrass over time. However, this trend is not linked to fire regime. Biomass on most plots has not recovered two to three years after fire.

Introduction

Nonnative grasses alter fire regimes in a variety of systems (D’Antonio and Vitousek 1992). Among the three requirements for fire (fuel, oxygen, and heat), introduced grasses may alter the fine fuel component; more specifically they can change fuel continuity, abundance, or composition and in turn alter the size, frequency, and intensity of fire. For example, in the eastern Sonoran Desert where fires had not occurred because of lack of fine fuels, invasion of buffle grass (*Cenchrus ciliaris*), red brome (*Bromus rubens*), and fountain grass (*Pennisetum setaceum*) destroyed native plant communities where fire-sensitive species exist (e.g., Schmid and Roger 1988). On some sites in the Great Basin, cheat grass (*Bromus tectorum*) stands have replaced sagebrush communities by increasing fire frequency and size thus preventing recovery of fire-sensitive sagebrush (Whisenant 1990). In these areas where fire had about a 30-year return interval a majority of grassland plant species resprouted after fire or established quickly from the seed bank and were gradually replaced by species that are less fire tolerant. Thus, nonnative grasses that recover quickly and exclude native species may increase fire frequency. In addition, nonnative grasses may increase fire intensity in fire-adapted systems. An African grass, *Melinis multiflora*, introduced into the Brazilian savanna produces resinous biomass that can burn in 95% relative humidity and prevents regrowth of native species (Klink and Moreira 2002). In these ways, nonnative grasses may alter fire regimes, including fire spread, frequency, and intensity. These changes may induce a positive feedback whereby the nonnative grass is benefited by and influences fire regimes to the detriment of the native plant communities (D’Antonio and Vitousek 1992).

Prior to Anglo settlement, fire in semi-desert grasslands occurred with a mean frequency of about 10 years (McPherson 1995). Unlike wetter grasslands such as the tallgrass prairie, semi-desert grasslands are constrained by erratic precipitation and produce relatively little fine fuel. Additionally, semi-desert grasslands support a discontinuous fuel source because the

communities are dominated by perennial bunchgrasses that are widely spaced. The influence of nonnative grasses on fire regimes in this system depends on site characteristics. Upland sites support a discontinuous fine fuel layer of bunchgrasses because soils typically are shallower and precipitation tends to run off. Bottomlands have deeper soils than uplands and water tends to collect in these areas, thereby supporting considerable biomass. Historically, fires likely could spread through these areas more frequently than on uplands because bottomlands were covered by a continuous fine fuel source and often had sufficient soil water to allow grasses to recover quickly. As a result, nonnative grasses are expected to have a greater influence on fire frequency and intensity on uplands than on bottomland sites.

In southeastern Arizona, Lehmann lovegrass (*Eragrostis lehmanniana*), a nonnative perennial grass, was introduced in the 1930s for livestock forage and erosion control. Lehmann lovegrass may have a positive feedback with fire because it produces more biomass than many native grasses (Cox et al. 1990b) such as *Aristida purpurea* and *Hilaria belangeri* and its germination is enhanced by fire (Ruyle et al. 1988). Lehmann lovegrass originated in a fire-dominated system in Southern Africa and now covers a large portion of the American Southwest. Upland sites with shallow soils appear to be heavily dominated by Lehmann lovegrass, whereas bottomlands are occupied by native species with higher biomass, for example, Sacaton (*Sporobolus wrightii*) (personal observation). The germination and growth characteristics of Lehmann lovegrass may influence fire regimes. In dry summers, Lehmann lovegrass can produce about four times as much green biomass as native species (Cox et al. 1990b). Accumulation of old-dead standing biomass from perennial grasses may be significant when summers are dry and termites (*Gnathamitermes perplexus*) are relatively inactive (Cox 1984). Following fire, Lehmann lovegrass rapidly establishes from the seed bank (Biedenbender and Roundy 1996; Ruyle et al. 1988; Sumrall et al. 1991). Additionally, under well-watered conditions this nonnative grass can double its biomass in less than one

week, whereas native grasses may require up to four weeks and when drought conditions were imposed, its maximum relative growth rate did not decline (Fernandez and Reynolds 2000). Thus, Lehmann lovegrass and fire appear to be part of a positive feedback cycle whereby large amounts of biomass contribute to a fine fuel source that promotes fire, and rapid germination and recovery following fire encourages rapid fire-return intervals. In this study we investigated the effect of fire season on relative biomass of Lehmann lovegrass to evaluate this apparent positive-feedback cycle. We expected that if a positive feedback exists then Lehmann lovegrass would be enhanced by fire at the expense of native plant biomass. We also expected that spring fires would harm native plants more than summer fires, the timing with which native species evolved, thus providing an opportunity for Lehmann lovegrass to increase.

Methods

Study Sites

Our experiment was established in grasslands and mesquite (*Prosopis velutina*) savannas at the base of the Huachuca Mountains (31° 34' N, 110° 26' W) of southern Arizona. Elevations range from 1,420 to 1,645 meters, and about two-thirds of the average annual precipitation of 440 mm falls between July-October and 20% falls between December-March (NOAA 1992). The region is characterized by a hot, dry period between late March and early July prior to the onset of seasonal "monsoons." The most recent fires at our sites occurred 11 to 24 years ago. Few livestock have grazed at Fort Huachuca Military Reservation since the late 1800s, and livestock have been excluded since 1950.

Experimental Design

Our experiment has a full-factorial treatment structure. Extant plant community (described below) is the whole-plot factor (levels: native, mixed, Lehmann), and burn season is the sub-plot treatment (spring fire, summer fire, no fire).

Plot Selection and Allocation

In the summer of 1999, we chose 18 sites at FHMR, 6 within each of 3 types of grassland communities, representing a continuum of plant invasion. Nonnative sites are grasslands dominated by Lehmann lovegrass (*Eragrostis lehmanniana*), a nonnative perennial grass. Native sites are grasslands dominated by native perennial caespitose grasses including *Aristida* spp., *Bothriochloa barbinodis*, *Bouteloua* spp., *Digitaria californica*, *Eragrostis intermedia*, and *Panicum* spp. Mixed sites are grasslands composed of a mix of nonnative and native species. Within each site we established 3 permanent 1-ha plots, each of which received 1 of 3 prescribed-fire treatments: no fire, spring fire, summer fire. We treated plots in 9 of 18 sites in each of 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 ($n = 2$).

In September and April we collected biomass of plants rooted in 25, 1 m x 0.5 m quadrats on each plot from 1999 to 2004. All vegetation was clipped at ground level (except perennial grasses, 2.5 cm) and separated into species. Samples were oven-dried at 65 °C for 48 hours. Data were analyzed in JMP (SAS Institute) using repeated-measures with biomass over time as the dependent variable and plant community type and treatment as independent variables. The experiment was a nested design with site nested within plant community (native, mix, nonnative) as the whole-plot factor and fire treatment as the sub-plot factor. In this paper we only present results of the proportion of Lehmann lovegrass at peak standing biomass (September sampling) on "Nonnative" and "Mixed" plots.

Results

The relative proportion of Lehmann lovegrass was not influenced by fire regime (table 1, MANOVA, $P > 0.1353$). There was a significant interaction between change in biomass over time and vegetation type (i.e., degree of dominance by nonnative grass) (table 1, MANOVA, $P < 0.0009$). On "Nonnative" plots (i.e., dominated by Lehmann lovegrass) treated in summer 2001, the proportion of Lehmann lovegrass declined during the first two growing seasons, but by the third growing season no differences persisted (figure 1a). There is an apparent overall increase in the proportion of Lehmann lovegrass over time, particularly in 2003 on "Nonnative" plots (figure 1). There was no change in proportion over time on "Mixed" plots (i.e., with an equal mix of Lehmann lovegrass and native grasses) treated in 2001; however, the variability in proportion across replicates increased in 2003 (figure 2a). Likewise, there was no change in the proportion of Lehmann lovegrass in response to fire on "Mixed" plots treated in 2002; there was an apparent increase in the proportion of Lehmann lovegrass in 2003, a particularly dry year (figure 2b).

Discussion

Other studies have examined the response of Lehmann lovegrass to fire. Cox et al. (1990a) examined the effect of fire treatments (winter, spring, summer, fall, and no fire) in communities dominated by Lehmann lovegrass on the Santa Rita Experimental Range, Arizona, and found biomass reduced for at least two years post-fire. However, in that study no pre-fire data or data on native perennial grasses are available for comparison of the relative proportions of native and nonnative grasses. Bock and Bock (1992) compared canopy cover of native grasslands and grasslands planted with Lehmann and Boer lovegrass prior to and after a wildfire burned one plot among the pair of native/nonnative sites. They found no change in the proportion of native grasses within nonnative sites or nonnative grasses found at native sites. An analysis of long-term trends in plant communities at the Buenos Aires National Wildlife Refuge also showed no relationship between fire and Lehmann lovegrass (unpublished data). Data described in this paper also indicate that in the 2-3 years following fire this nonnative grass did not increase, relative to native plant biomass, providing no evidence of a positive feedback. These results contrast with

Table 1—Proportion of Lehmann lovegrass biomass as influenced by vegetation type and fire season in grasslands of the Huachuca Mountains, Arizona. The analysis was a repeated-measures analysis of variance (MANOVA) with proportion of Lehmann lovegrass over time as the response variable and the independent variables are as follows: Vegetation Type (i.e., degree of dominance by Lehmann lovegrass) is the whole-plot factor, Fire Treatment is the sub-plot factor, and Site is nested within Vegetation Type. The entire experiment was replicated and the replicates are designated as 2001 and 2002.

	Year	F	Numerator DF	Denominator DF	P
Time	2001	32.7919	4	9	<0.0001
	2002	71.5554	3	10	<0.0001
Time*Veg Type	2001	5.8466	8	18	0.0009
	2002	4.6708	6	20	0.0040
Time*Treatment	2001	1.7193	8	18	0.1616
	2002	1.8744	6	20	0.1353
Time*Site[Veg]	2001	1.1901	24	32.607	0.3175
	2002	1.4900	18	28.77	0.1625
Time*VegType*Treatment	2001	1.1979	16	28.133	0.3275
	2002	0.8749	12	26.749	0.5805

a review of other studies that investigated feedbacks between fire and nonnative grass (D'Antonio and Vitousek 1992). In the short span of our study, fire did not accelerate dominance by the nonnative, Lehmann lovegrass.

Our study is the first large-scale experiment to explore the effects of fire season on plant communities across a gradient of invasion by Lehmann lovegrass. In the current paper, we examined the change in proportion of Lehmann lovegrass on plots containing greater than 40% biomass of this nonnative

(i.e., Nonnative and Mixed sites). If a positive feedback exists between fire and Lehmann lovegrass we would expect the proportion of nonnative biomass to increase over time on burned plots. Specifically, we expected that fire on plots with an equal mix of the nonnative and native grasses would result in an increase in the proportion of Lehmann lovegrass. We also expected that site characteristics would influence the proportion of Lehmann lovegrass after fire. We found evidence of a slight change in the proportion of Lehmann lovegrass on some

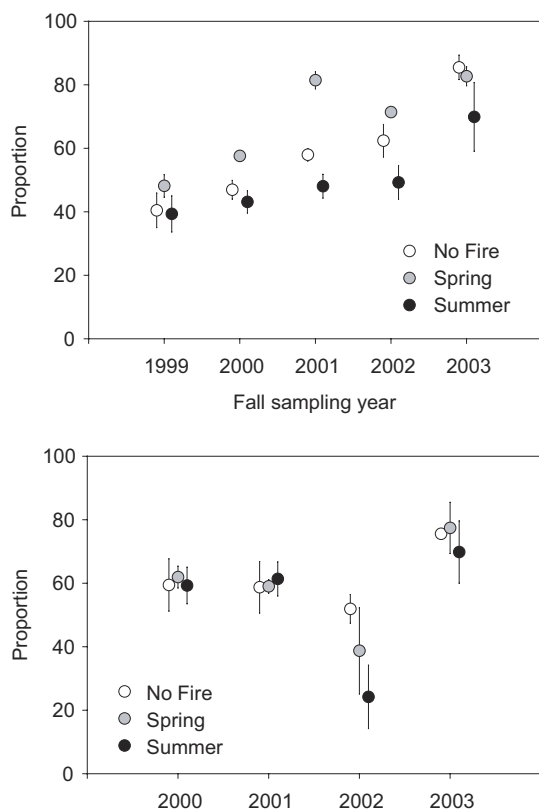


Figure 1—Proportion of Lehmann lovegrass (*Eragrostis lehmanniana*) on “Nonnative” plots dominated by Lehmann lovegrass burned in 2001 (figure 1a) and on plots burned in 2002 (figure 1b) in semi-desert grasslands at the base of the Huachuca Mountains, Arizona.

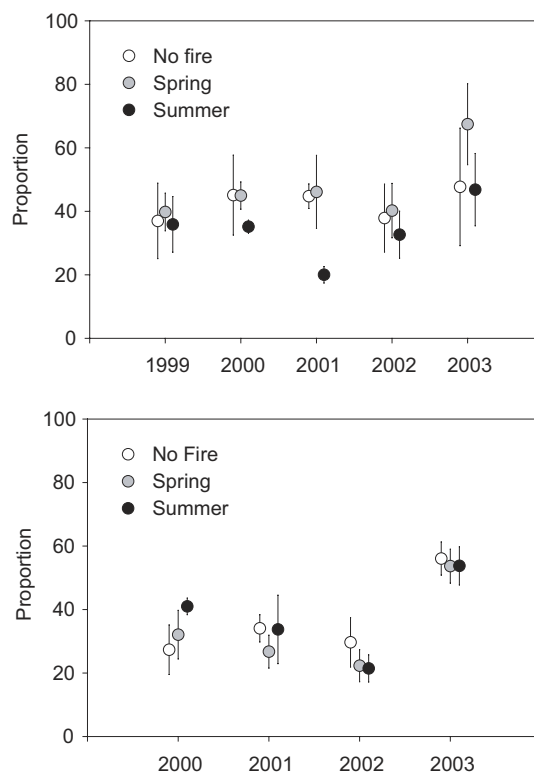


Figure 2—Proportion of Lehmann lovegrass (*Eragrostis lehmanniana*) on “Mixed” plots comprised of approximately equal abundance of Lehmann lovegrass and native grasses burned in 2001 (figure 2a) and on plots burned in 2002 (figure 2b) in semi-desert grasslands at the base of the Huachuca Mountains, Arizona.

plots (figure 1a) but the biological significance of this trend is unclear. However, the biomass on burned plots has not returned to pre-fire levels (unpublished data) so the relative proportions of native and nonnative grasses, especially in relation to site, may change as plants continue to grow.

Even if the proportion of Lehmann lovegrass to native plants is not altered by fire, scientists and land managers should continue to monitor its status and be cautious when incorporating fire into these systems. The data presented in the current paper explicate the interaction between nonnative grass and fire at very limited spatial and temporal scales. Effects of spring fires are largely unknown, especially for the many ecosystem functions and unnoticed species that are rarely monitored. A more appropriate management strategy would involve introduction of fires during the season with which native species evolved: early summer coincident with dry-lightning storms preceeding the “monsoon” rains. Native species have developed adaptations to fires that occur at a particular frequency, season, and extent, and reintroduction of the fire regimes with which these species evolved should assume high priority for those interested in maintaining high levels of biological diversity.

Reintroduction of ecological processes such as fire should be a relatively efficient and comprehensive strategy for retaining native species in extant ecosystems, albeit with two caveats about contemporary fires: (1) Contemporary fires often are unlike the fires with which species evolved and communities developed. A century of fire suppression, particularly in concert with the introduction of nonnative species such as Lehmann lovegrass, has changed the mix of species and wildland fuels in many of these systems. Lehmann lovegrass currently represents 30-90% of the total biomass in these grasslands and appears to be increasing over time. Fires in these “new” systems may favor a few nonnative species to a greater extent than they favor diverse native species, thus reducing biological diversity. (2) Anthropogenic activities have fragmented landscapes, and this fragmentation has blocked routes of dispersal. Former metapopulations no longer exist as recolonization sources for small, isolated populations, which may amplify adverse biodiversity effects of fires. Because of changes in species composition, fuel loads, and metapopulation dynamics, contemporary fires may extinguish small, isolated populations of many species in Southwestern ecosystems.

Another challenge to land managers in semi-desert grasslands is the inherent variability in these systems. Because erratic precipitation limits growth in semi-desert grasslands, fire effects can vary substantially as a function of weather conditions both before and after fire. For example, fires set during drought may require long recovery periods, create conditions that favor certain species over others, and result in increased erosion due to low vegetative cover. Some managers

may develop plans several years in advance to receive funding and approval (e.g., 10 years) and not consider the importance of flexibility in setting the time for prescribed fire. Often, they are unable to adapt their proposed activities at the most appropriate time, without risking losing the funding. Scientists can contribute to management of these “new” communities by exploring which factors contribute to changes in variability of plant community composition and by identifying thresholds for recovery of native grasslands.

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