The Effects of Fire Frequency and Firebreaks on the Abundance and Species Richness of Exotic Plant Species in Coastal Sage Scrub

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Abstract

The abundance and richness of exotic forb and grass species significantly increased with higher fire frequency in coastal sage scrub. The observed changes in abundance and richness support the compensation hypothesis (Petraitis et al. 1989) recently used by Tilman to develop the spatial competition hypothesis (1994), suggesting that species with a greater investment in reproduction (exotic annuals in this study) will proliferate when disturbance processes occur at greater frequencies, while the superior competitors (native shrubs) will dominate the system when disturbance frequency is low. Previous studies in coastal sage scrub by Westman (1981) and Allen et al. (1996) indicate that oxidant levels and nitrogen deposition can be significant factors influencing exotic plant abundance and species richness. Keeley (1982) has postulated that patterns of oxidant concentration (and probably nitrogen deposition, the author) have similar spatial distributions as fire frequency, with highest levels of both associated with urban areas. This study was conducted in a region of low oxidant levels and nitrogen deposition, yet patterns of exotic abundance and richness were found and related to fire frequency. The effect of firebreaks as potential exotic seed sources was also examined. Sites near firebreaks did not have greater exotic biomass. Seed banks at these sites did have significantly more *Avena barbata* (wild oat) and fewer native forb seeds. Results indicate the importance of managing ecosystem processes (fire regime) and indicate that the coastal sage scrub system may be susceptible to degradation if exotic invasion and fire disturbance are linked processes.

Introduction

The invasion of exotic grasses and forbs into the coastal sage scrub (CSS) system poses two main threats: competitive interactions with native species and alteration of the processes that control ecosystem functioning (the fire disturbance regime).

Competitive effects:

Many studies have demonstrated that exotic grasses are good competitors against herbaceous and woody species (Bush et al. 1989, Cohn et al. 1989, Knoop and Walker 1985, Litav et al. 1963, Schultz et al. 1955, Van Auken and Bush 1988). Specifically, rapidly growing grasses can reduce soil light (Tang et al. 1988, Thompson and Harper 1988), compete for water more effectively (Da Silva and Bartolome 1984, Davis and Mooney 1985, Eliason 1995), and use available soil nutrients (N and K) (Elliott and White 1989, Caldwell et al. 1981, 1985).

Competitive effects of exotic grasses have been shown to decrease seedling survival of the native shrubs *Baccharis pilularis* (Da Silva and Bartolome 1984, Davis and Mooney 1985) and *Artemisia californica* (Eliason 1995).

Ecosystem effects: interaction of fire and exotics

Annual forbs and grasses complete their life cycle early in the growing season. This creates large amounts of standing dead material that burns readily due to a high surface/volume ratio and a low moisture content. Fine size classes of fuel (grasses and forbs) ignite and spread fires under a broader range of conditions than woody material or leaf litter (Rundel 1981).

A number of field studies have examined the effects of exotics on fire regimes. Of particular relevance are the studies relating invasion of exotic grasses to increases in fire frequency. In Hawaii, the number of fires increased from 27 fires to 58 fires and the average fire size increased from 4 ha to 205 ha after a twenty year period in which grasses invaded (Smith 1985, Smith and Tunison 1992). In the Great Basin the pre-invasion fire return rate was 60 - 100 years, while after invasion it dropped to between 3 - 5 years (Whisenant 1990).

High cover of exotic species in shrub systems also allows "extreme events" to occur, such as fires in consecutive years (Zedler et al. 1982). Such events can abruptly change successional patterns, even in fire adapted community types.

The purpose of this study was to examine patterns of exotic species abundance and richness to determine if high exotic cover was correlated with fire frequency. Of particular concern was the potential contribution of firebreaks to the spread of exotic species within the CSS system. In addition, other environmental variables (Table 1) were examined to see if these affected exotic species distributions.

Methods

Study site

The study was carried out on Marine Corps Base Camp Pendleton, in northern San Diego county, CA. The Base has over 35,000 acres of CSS which represents approximately 1% of the remaining CSS habitat in California. Fire is a common occurrence on the Base, providing a unique opportunity to examine the effects of fire frequency on natural vegetation.

Table 1.

Summary of data collected.

Dependent variables	Independent variables
Dry biomass g/m2	Fire frequency: 0, 1, 2. 3, or 4 fires in 12 years
Species richness	Years since last fire, 5 classes: 3-4, 5-6, 7-8, 9-11, & 12+
	Length of most recent fire interval, 5 classes: 1, 2-3, 4-6, 7-11, & 12+
	Distance to seed source, 2 classes: adjacent or far from fire break (>500 m)
	Aspect, 6 classes: N, E, SE, S, SW, W
	Slope of plot (%)
	Light penetration through canopy (LICOR canopy analyzer)
	Subjective canopy cover estimate 1 (open) to 5 (closed)
	Soil variables (texture, TKN, total car bon, water holding capacity at 1 atmosphere. and pH)
	Distance to ocean
	Elevation

Methods

Biomass of exotic species, cover of native vegetation, and environmental variables (Table 1) were measured every 10 m along a 100 m transect line for 34 sites in CSS. The 34 sites were stratified in five fire frequency classes varying from 0 to 4 burns in the 12 year period from 1983 to 1995 (areas with burns from 1993 to 1995 were excluded from the site selection process, Figure 1). Five plots within each fire frequency class were located adjacent to firebreaks and two plots per class were at least 500 in away from firebreaks. Sampling and soil collection occurred in August 1995 after seed set.

Soil samples from two plots in each fire frequency X distance to firebreak class were germinated in a greenhouse the following spring. Soil analyses were carried out on soil samples: texture analysis, Total Kjedahl Nitrogen (TKN), percent total carbon, pH, and water holding capacity at 1 ATM.

One-way ANOVA's and Spearman rank correlation tests were used to test for correlations between predictor variables and the exotic plant response variables. Canonical Correspondence Analysis (CCA), a multivariate ordinal technique, was used to examine the influence of multiple predictor variables on the distribution of exotic species in ordinal space.

Results

Field study

The biomass and species richness of both exotic forbs and exotic grasses increased with increasing fire occurrence as measured by the fire frequency variable (Figure 2). This pattern of response clearly indicates that repeated fires offer opportunities for the establishment of exotics and favor their growth. The response of the forbs was much larger than that of the grasses, with a biomass change of 5.1 g/m^2 to 52.7 g/m^2 (1033% increase) from 0 fires to 4 fires in a twelve year period, compared to a change of 18.2 g/m2 to 30.0 g/m^2 (164% increase) for the grasses.

The exotics showed a weaker response to year since last fire (YSLF). Decreasing non-native grasses biomass was correlated with increasing YSLF (R2 = .18, p = .03), but forbs were not (R2 = .04, p = .31).

There was a clear spatial component to the biomass response of exotics. The increase in biomass was apparent only directly adjacent to the firebreaks (0 m and 10 m from the firebreak), while observations at 20 m and further away from the transect line were comparable to values observed in transects not adjacent to firebreaks (Figure 3). This indicates that firebreaks have a very limited influence on the biomass of exotic species. Exotic biomass for sites adjacent to firebreaks was 44.5 g/m^2 and 45.4 g/m^2 for sites located far from firebreaks.

Greenhouse study

Seedling abundance data indicated that exotic grasses and forbs have different requirements for reproductive success. The exotic forbs responded strongly to fire regime. A significantly greater number of seedlings were observed for higher fire frequency sites (p = .004, Fig. 4), seedlings were less abundant when time since fire was long (YSLF, p = .036), and more seedlings were observed when fire interval was short (p = .002).

Exotic grass species, however, were not correlated with fire variables, but had strong correlations with environmental variables (Figure 4). Exotic grass seeds were more abundant on soils with higher percent total carbon (p = .04), higher TKN (p = .02), and greater water holding capacity ($p < .01$).

Distance to firebreak only influenced seedling abundance for native species: sites adjacent to firebreaks had significantly lower numbers of native forb seeds (p = .04) and marginally lower numbers of shrub seeds (p = .18). Results from the Canonical Correspondence Analysis confirm the relationships indicated by one-way ANOVA tests (Figure 5). The fire frequency vector is associated with exotic forbs that had large numbers of seeds at high fire frequency sites (*Centaurea melitensis* and *Hirschfeldia incana*) as well as native shrubs that responded negatively to high fire frequency (*Artemisia californica* and *Eriogonum fasciculatum*).

Discussion

Results strongly indicate that fire frequency is the main factor controlling the abundance and richness of non-native forb species in coastal sage scrub for the study area. The change in dry biomass from 5.1 g/m^2 to 52.7 g/m^2 is large enough to have significant effects on resource utilization and energy flows through the system. Non-native grasses also increased with greater fire frequency, but the biological significance of changing from 18 g/m^2 to 30 g/m^2 dry weight is questionable, since the grasses are already common in the system. The combined response of increased exotic biomass, however, increases the probability of wildfire by providing more fine fuels in vegetation that is repeatedly burned. The alteration of the natural disturbance regime poses threats not just to individual species, but to the system as a whole. Ultimately it can lead to conversion from shrubland to exotic dominated grasslands.

Several other factors will exacerbate this problem:

- High levels of nitrogen deposition seem to favor growth of non-native forb and grass species and possibly harm native shrub species (in particular *Artemisia californica*, Allen et al. 1996).

- Oxidant levels may be reducing the fitness of some dominant species in the CSS system (in particular *Artemisia californica*, Westman 1981).
- Past increases in global temperature of only 1-2°C have reduced the time between fires by one half (Clark 1988).
- Recent US border policies have pushed immigration routes to remote canyons and other "wild" areas in San Diego county greatly increasing fire ignition rates.

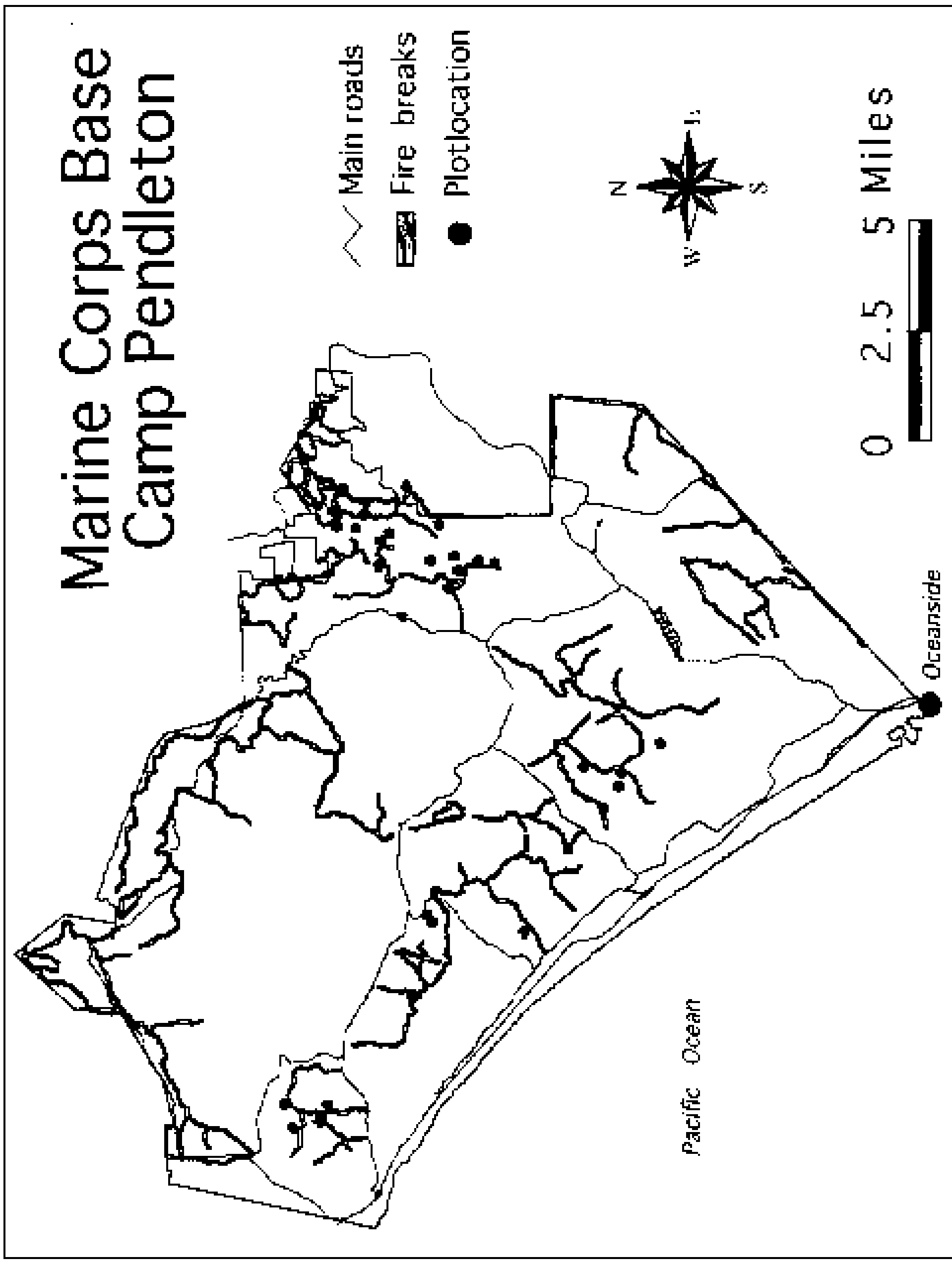

Figure 1. Location of field sites on Camp Pendleton.

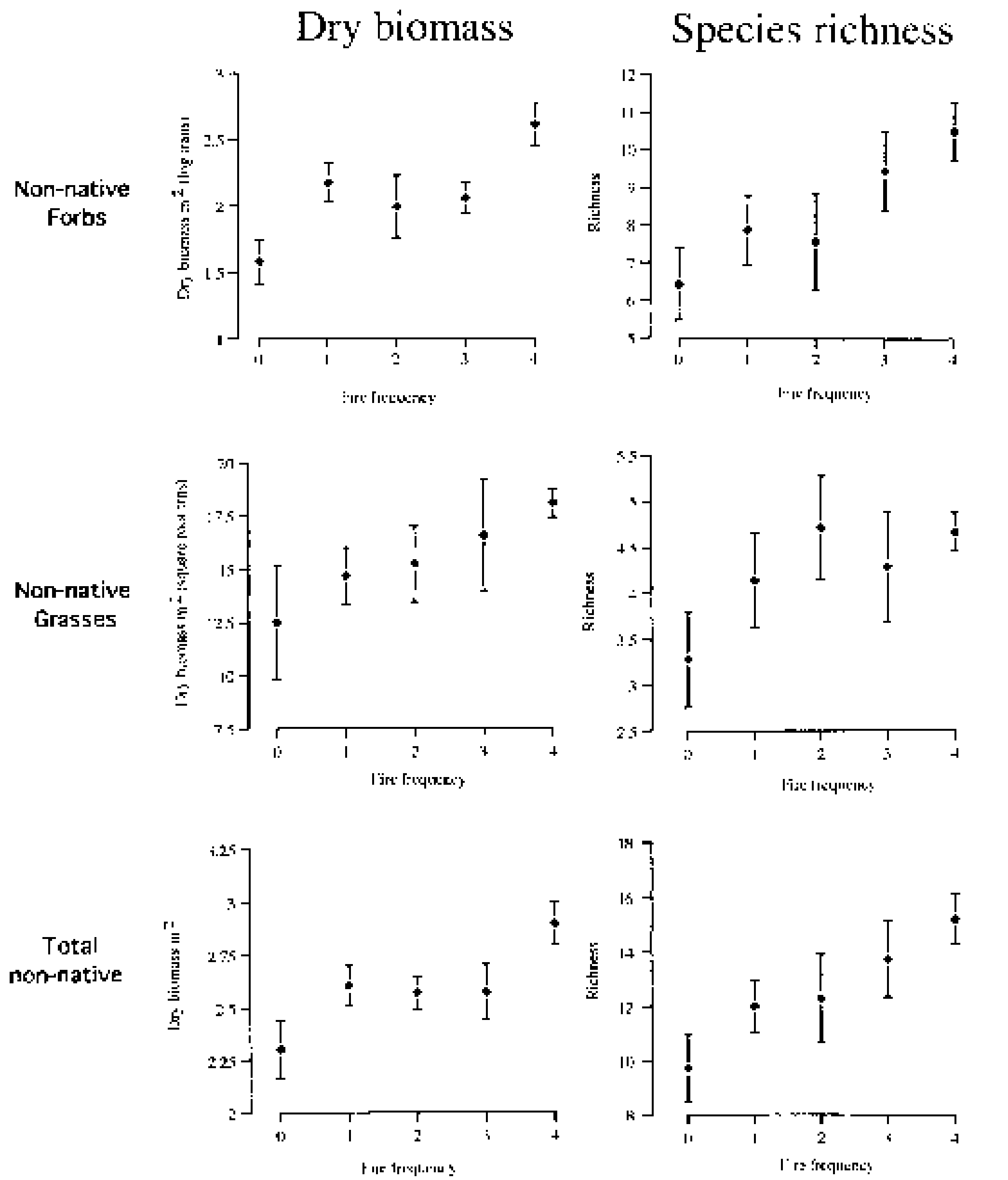

Figure 2. Dry biomass and species richness by fire frequency class.

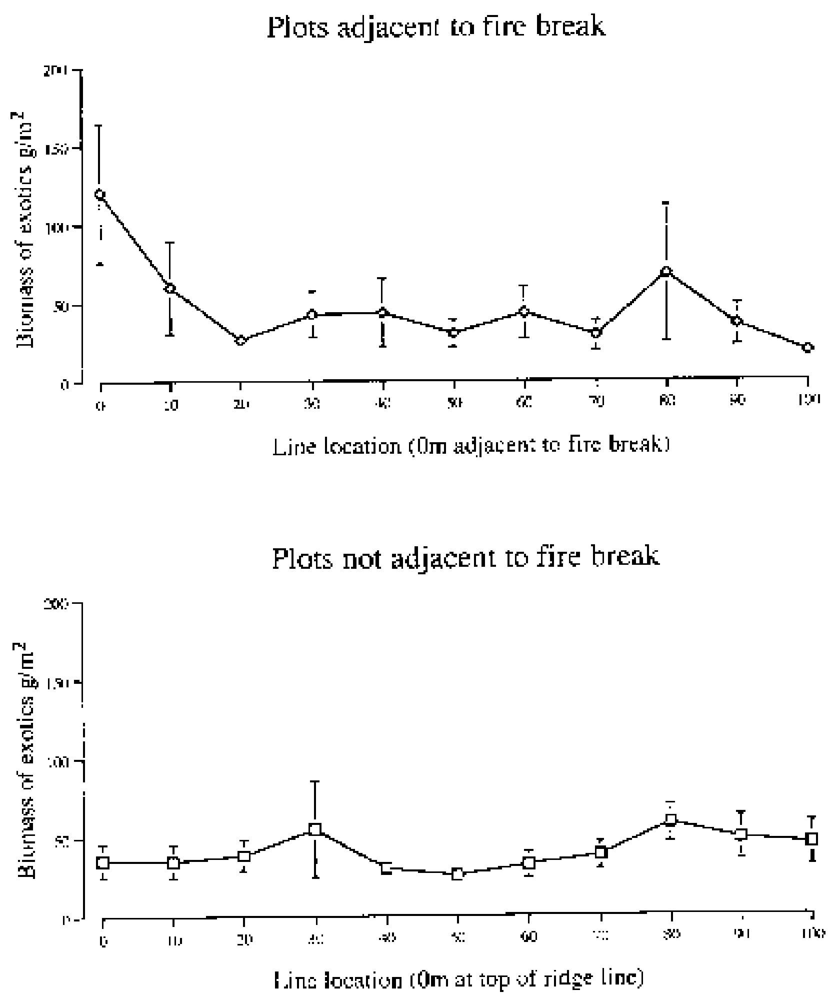

Figure 3. Within transect variation of biomass for sites adjacent to firebreak and far from firebreak.

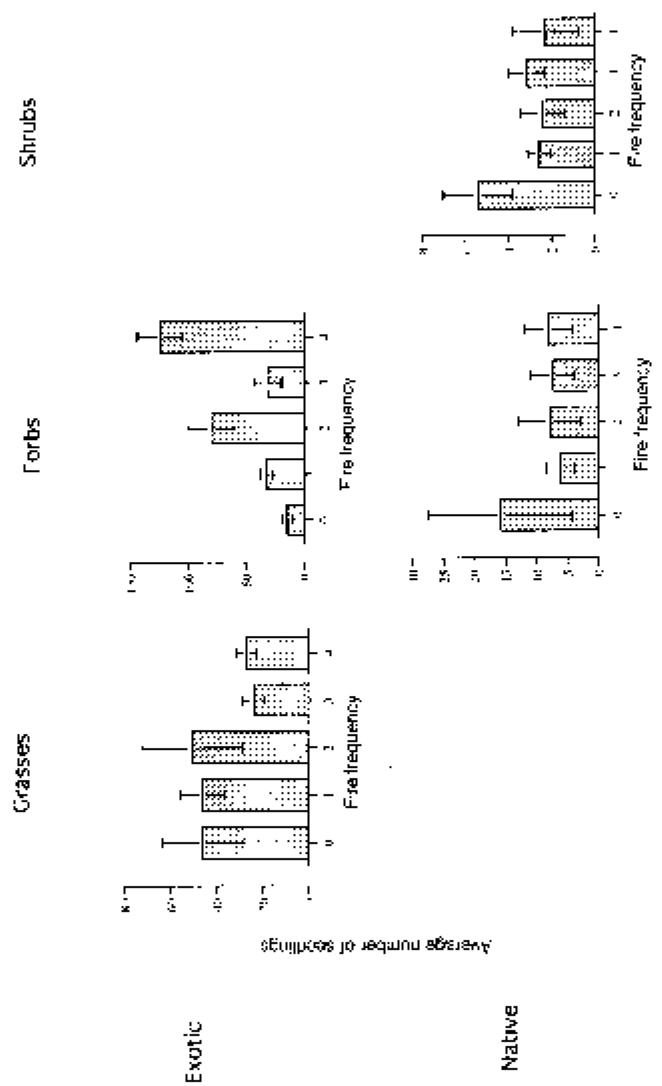

Figure 4. Mean number of seedlings on each greenhouse tray by fire frequency class (0 to 4 fires in a twelve year period). Each greenhouse tray = 330 cm^2 soil surface area in the field.

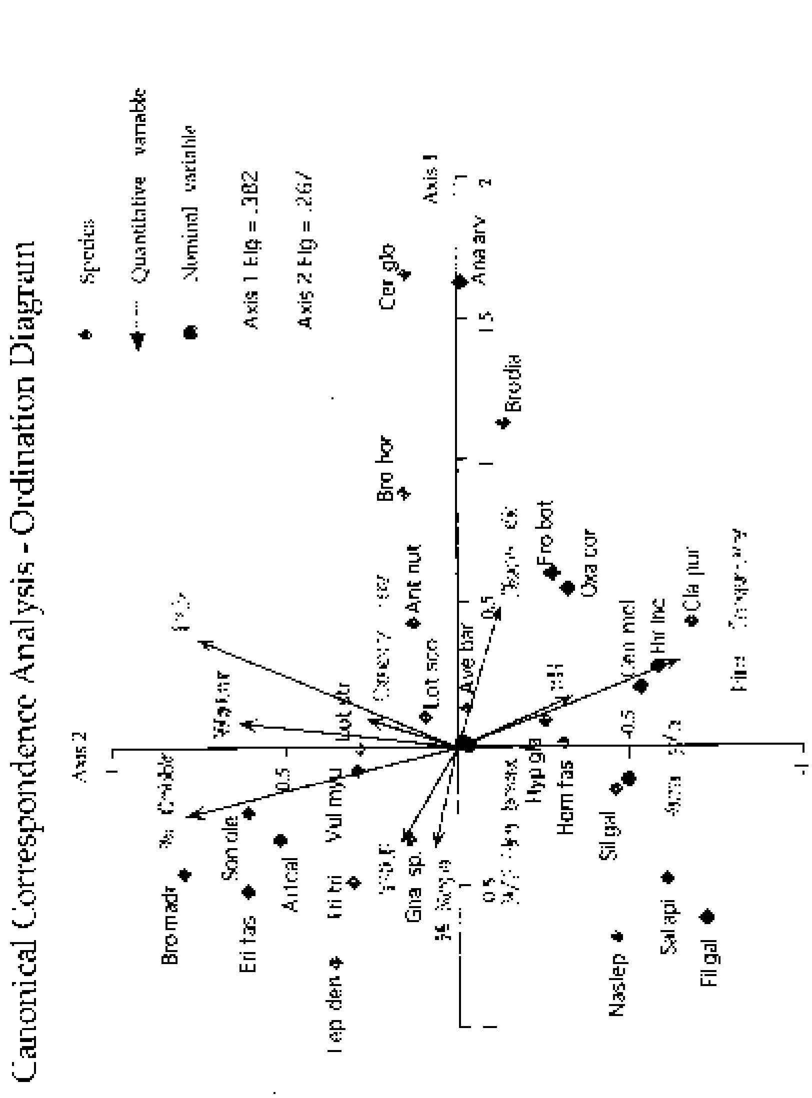

Figure 5. Canonical Correspondance Analysis output. Montecarlo test on model p < .01. Ana arv= Anagallis arvensis, Ant nut= Antirrhinum nuttallianum, Art cal= Artemesia californica, Ave bar= Avenabarbata, Bro dia= Bromus diandrus. Bro hor= Bromus hordeaceus. Bro madr= Bromus madritensis, Cen mel= Centaurea melitensis, Cer glo= Cerastium glomeratum, Cla pur= Clarkia purpurea. Eri fas= Eriogonum fasciculatum, Fro bot Erodium botrys, Fil gal= Filago gallica. Gna sp.= Gnaphalium sp., Hem fas= Hemizonia fasciculatum, Hir inc= Hirschfeldia incana, Hyp gla= Hypochoeris glabra, Lep den= Lepidium densiflorum, Lot sco= Lotus scoparius, Lot str Lotus strigosus, Nas lep= Nasella lepida, Oxa cor= Oxalis corniculata, Sal api= Salvia apiana, Sil gal= Silene gallica, Son ole= Sonchus oleraceus, Tri tri= Trifolium tridentatum, and Vul myu= Vulpia myuros.

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