Effect of fire and grazing on invasive species in northern mixed grass prairie[1]

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Abstract

Invasive plants pose a threat to pristine and natural mixed grass prairie so managers seek to control them. On the basis of experience in the tall grass prairie, some hypothesize that they may be controlled with fire and grazing. The fact that the invaders are cool season species in a cool season prairie, rather than cool season species in a warm season matrix, reduces the possibility of selectively treating them- - and casts doubt on the applicability of these tools in mixed grass prairie.

Long-term management experiments at Lostwood and Des Lacs National Wildlife Refuges (NWR) provide a near ideal opportunity to test these hypotheses. The replicated factorial experiment includes six burning treatments (0-6 burns) crossed with two grazing (grazed and ungrazed) treatments. By subsampling each unit, one can estimate the local (bottom, N-slope, S-slope, and hilltop) and regional (North Dakota vs. Montana) effects of water availability. We field-sampled units to compare the spread of nine species - - i.e., the long distance dispersal (frequency) and clonal spread (cover) - - among these treatments. Responses to various aspects of fire and grazing were measured with multiple regression. The species studied included two perennial grasses (*Bromus inermis* and *Poa pratensis*), three woody plants (*Symphoricarpos occidentalis*, *Populus tremuloides*, and *Elaeagnus commutata*), two perennial forbs (*Cirsium arvense* and *Euphorbia esula*) and two biennial forbs (*Melilotus officinalis* and *Tragopogon dubius*).

The growth (+) of invaders with very different ecological strategies were highly correlated (p=0.0001-0.01) with aspects of environment, grazing, and fire. The responses were, however, not strong, that is, slopes of the regression lines were low and little of the variance was accounted for (low r^2). In addition, the responses were inconsistent between the two nearby refuges. Thus, while managers use fire and grazing for other reasons (e.g., management of woody biomass, litter, and wildlife habitat), we see no evidence that either is useful for weed control.

Keywords. Weed invasion, weed control, exotics, fire, grazing, mixed grass prairie, Lostwood National Wildlife Refuge, Des Lacs National Wildlife Refuge, *Bromus inermis*, *Poa pratensis*, *Symphoricarpos occidentalis*, *Elaeagnus commutata*, *Populus tremuloides*, *Euphorbia esula*, *Cirsium arvense*, *Melilotus officinalis*, and *Tragopogon dubius*.

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Acknowledgements

CHAPTER 1

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in northern mixed grass prairie, Lostwood NWR, N Dakota.

Abstract

To measure the effects of fire and grazing on weeds in northern mixed grass prairie, we analyzed a management experiment conducted at Lostwood National Wildlife Refuge (NWR) in northwestern North Dakota. The experiment included six fire treatment (0-6 prescribed burns) and two grazing treatments (none and light) in a replicated factorial design. The effects, on nine weed species, of habitat (bottoms, north slopes, south slopes, and hilltops), fire (burn vs. no burn, number of burns, season of burn, years since burn), and grazing (none of light, number of grazes) were examined with multiple regression. The weeds include exotic grasses (*Bromus inermis* Leyss. and *Poa pratensis* L.), woody natives (*Symphoricarpos occidentalis* Hook., *Elaeagnus commutata* Bernh., *Populus tremuloides* Michx.), perennial exotic forbs (*Euphorbia esula* L. and *Cirsium arvense* L.), and biennial exotic forbs (*Melilotus officinalis* L. and *Tragopogon dubius* L.).

While there were many significant trends (p=0.00001-0.1), they were always weak. Thus, we conclude that, while neither fire nor grazing successfully control weeds in the mixed grass prairie, the manager will use our data to estimate the effects, on weed presence, of fire and grazing applied for other purposes.

Key words. Weed invasion, weed control, exotics, fire, grazing, mixed grass prairie, *Bromus inermis*, *Poa pratensis*, *Symphoricarpos occidentalis*, *Elaeagnus commutata*, *Populus tremuloides*, *Euphorbia esula*, *Cirsium arvense*, *Melilotus officinalis*, *Tragopogon dubius*, Lostwood NWR, North Dakota.

Introduction

Northern mixed grass prairie is threatened by both exotic and native invasive species (Samson and Knopf 1996, Larson et al. 2001). Native shrubs (e.g., *Symporicarpos occidentalis*) and exotic grasses (e.g., *Bromus inermis* (Blankespoor 1987, Willson 1992) and *Poa pratensis*) are primary threats. Less threatening invaders include other woody natives (e.g., *Elaeagnus commutata*), exotic perennial forbs (*Euphorbia esula* and *Cirsium arvense*) and exotic biennial forbs (*Melilotus officinalis* and *Tragopogon dubius*). We consider fire and grazing as management tools.

Woody shrubs are increasing on National Wildlife Refuges (NWRs) and other rangelands of the northern mixed grass prairie (Weaver and Plaggemeyer 2004). Two environmental changes that may be responsible are fire suppression and reduction in cattle/buffalo grazing. Fire reduction should favor shrubs because they are retarded by fire. Simultaneously,

cattle grazing might either favor shrubs (by reducing grass/forb competition) or reduce them (by trampling). Thus, we hypothesize that reintroduction of fire will reduce shrub presence/dominance and that light grazing will have no effect on shrub presence/dominance.

Exotic herbs, especially *B. inermis* (Looman 1969, Wilson 1989, Romo et al. 1990, Blankespoor and Larson 1994, Willson and Stubbendieck 2000) and *P. pratensis*, are also increasing. Exotic grasses might also be managed using prescribed fire (Old 1969, Sather 1988). Spring burning controls these grasses in tall grass prairie (Willson 1992, Willson and Stubbendieck 2000), because it damages the cool season invaders before warm season dominants become active (Grilz and Romo 1994). Efforts by managers to transfer this practice from tall grass to mixed grass prairie are likely to fail because weeds and natives of northern mixed grass prairie have the same phenology (Willson and Stubbendieck 2000). That is, while a spring fire may damage cool season exotics, selection against them will be less than in tall grass prairie, because cool season natives will also be damaged (Curtis and Partch 1948, Hobbs and Huenneke 1992, Masters and Sheley 2001, Shay et al. 2001). Fire may actually favor the rhizomatous exotics (Kirsch 1974, Blankespoor 1987, Grilz and Romo 1994, Willson and Stubbendieck 1996) because rhizomatous plants are generally less susceptible than the bunch-grass natives. Thus, we hypothesize that fire will have neutral to positive effects on exotic grasses.

Exotic herbs might also be managed with grazing. Grazing should select against exotics if they are more palatable or if it is applied in a season when they are more palatable/actively growing. Since it is believed that spring palatability declines from *B. inermis* to *P. pratensis* to natives and fall palatability declines from *P. pratensis* to natives to *B. inermis*, we expect spring grazing to select against *B. inermis* and fall grazing to select against *P. pratensis*. Considering these two factors, we hypothesize that spring grazing will have neutral to negative effects on exotic grasses.

We tested our hypotheses by sampling a long tern (30 year), replicated, factorial management experiment on the Lostwood NWR, North Dakota. We used regression techniques to simultaneously consider the effects of two grazing treatments (grazed and ungrazed) across six burning treatments (0-6 burns; Table 1.1). Weed responses were measured separately on four increasingly xeric habitats (bottoms (B), north slopes (N), hilltops (T), and south slopes (S)) to facilitate extrapolation to other sites and regions.

Methods

Experimental design/approach. The division of the refuge into management units with different well-recorded fire and grazing histories provided a factorial management experiment suitable for measuring the effect of fire and grazing on unwanted shrubs/trees and exotic herbs of mixed grass prairie. The management units included 27 similar units (e.g., vegetation, soil type) that differed primarily in the number of prescribed burns (0-6) and the level of grazing (grazed or ungrazed). Treatments were surprisingly well balanced among the treatment cells (Table 1.1). The burns were typically conducted either during April-May (spring burn) or August-October (fall burn). Grazing was on a three-year rotation with two passes per year.

The rolling topography of the refuge allowed us to nest habitat types (bottoms, north-slopes, hilltops, and south-slopes) in each treatment unit and therefore both to compare treatment effects on landscape facets of the refuge and to extrapolate our results to other areas, i.e., from south-slopes to drier areas in the region (e.g., eastern MT) and from north-slopes to moister areas in the region (e.g., central ND).

Study area. Lostwood NWR includes 109 km^2 (10,900 ha) of northern mixed-grass prairie on the rolling hills near Stanley in northwestern North Dakota. Lostwood NWR is on the Missouri Couteau, the terminal glacial moraine of the continental glacier, and is thus characterized by knob-and-kettle topography. Its altitude ranges from 685-747 m. The primary vegetation is thus a grassy matrix in which over 5000 wetlands are embedded.

Lostwood NWR's climate is semi-arid with mean annual precipitation of 42 cm. We sampled in 2001 and 2002. 2001 had near-average precipitation, that is, with 39.8 annual cm with 66% falling during March-June. 2002 was somewhat drier, that is, with 29.1 cm with 40% falling during March-June.

Lostwood NWR's grassy matrix is typical of mixed grass prairie of the northern Great Plains (Kuchler 1964). Dominant indigenous species are needlegrasses (*Stipa* spp.) and wheatgrasses (*Agropyron* spp.). Exotic grasses (primarily *B. inermis*, *P. pratensis*), woody natives (primarily *S. occidentalis*, *E. commutata*, and *P. tremuloides*) and exotic forbs are invading.

Beginning in the 1850s, northwestern North Dakota was subjected to extensive ranching, intensive cultivation, and some coal mining.   Prairie regulators were modified; fire suppression was initiated, grazing initially increased [probably] and was then removed, at least on the refuges. Grazing and agricultural activities - - except for cooperative farming and haying on limited previously-cropped areas - - ceased on Lostwood NWR after its establishment in the 1930s. The effects of long-term fire and grazing suppression are seen in the landscape today, especially in the spread of woody vegetation and exotic grasses *Bromus inermis* and *Poa pratensis*. The goal of NWRs in North Dakota - - to preserve and enhance the natural integrity and diversity of habitat and sanctuary for migratory birds and other wildlife (16 U.S.C. § 715d; Migratory Bird Conservation Act) species of the northern Great Plains - - is challenged by a land management history that has supported this invasion.

Procedures. To compare weed establishment and success in four habitats, six fire treatments, and two grazing treatments, we sampled five random points in each habitat (B, N, T, S) across 22 to 27 management units (in 2001 and 2002, respectively). Data were collected from 176 sites in 2001 and from 324 sites in 2002 on Lostwood NWR.

The random points were located by creating a digital elevation model (DEM) of the area, mechanically identifying habitats, and randomly sampling them. With NASA sponsorship, Ikonos created a 16 x 16 m DEM. R. Aspinall (Geography Head, Arizona State Univ, Tempe AZ) divided the area into bottoms, north-slopes, hilltops, and south-slopes and identified random points in each habitat of each unit studied. Roadsides and remote areas were stratified out. An excess of points (10) was chosen so misclassified points could be omitted. For sampling, the random points were located in the field with a

GPS instrument (Trimble Pro-X or Garmin eTrex Vista) and accepted/rejected after measuring slope and aspect.

The vegetation at each site was sampled along a 20-m transect centered on the random point, running along the contour, and with constant aspect. Ten 1x1 m quadrats, located on alternate meters of the transect, were observed for presence and cover. Cover was ocularly measured to the nearest percent. Supplemental characterization of the vegetation was made by the method of Grant et al. (2005); the cover of regional 'community types' was recorded in a 10 cm x 20 m belt transect centered on the random point and running along the transect axis.

We investigated/measured the success of nine invasive species. We defined invasive species as non-native or native species that can potentially dominate an area, eventually replacing native grasses and forbs. We focused on two exotic perennial clonal grass species: [smooth brome (*Bromus inermis* Leyss.) and Kentucky bluegrass (*Poa pratensis* L.)]; three native woody species that increase with the absence of fire [shrubby western snowberry (*Symphoricarpos occidentalis* Hook.) and silverberry (*Elaeagnus commutata* Bernh. ex Rydb.)

and arborescent quaking aspen (*Populus tremuloides* Michx.)]; two noxious perennial clonal forbs [leafy spurge (*Euphorbia esula* L.) and Canada thistle (*Cirsium arvense* L.)]; and two exotic biennial forbs [yellow sweet clover (*Melilotus officinalis* L.) and goatsbeard (*Tragopogon dubius* L.)]. The first three were chosen for their immediate management concern and the remaining six were selected as contrasting life forms.

Two indices of success were used. First, the invasiveness of a weed at a site was indexed with frequency, the percent of the 10 quadrats sampled that were occupied by the weed. That is, an invasive weed has a high frequency (number of occupied plots/10) and a week invader has a low frequency. Second, the capacity of a weed to dominate a site it invaded is indexed by its average cover in occupied quadrats at the site, that is average dominance was only measured across quadrats in which the plant established. To illustrate, a biennial weed (e.g., *Tragopogon dubius*) can have a high frequency and a low cover, while a clonal grass (e.g., *Bromus inermis*) whether it has a high or low frequency often has a high cover.

Statistical analysis. In graphical analysis, plant response was plotted against a gradient from 0 (no fire in more than 80 years) to 6 (many burns, the last burn within 1-2 years). Separate plots were made for grazed and ungrazed sites. For the 'technical analysis' we used multiple regression analysis to quantify the relationships between invasive weed presence (frequency and cover) and treatment (habitat, fire, and grazing). Habitat had

four topographic facets (bottom, north, south, and top). Fire had several facets (number of burns, season of burn, years since burn) and grazing had two facets (+/- and number of grazes). Percent cover values were untransformed and assumptions of normality could be assumed based on the central limit theorem, that is sample sizes were large (e.g., n = 5,000). Because effects of fire, grazing, and habitat were less than expected, the 'statistical significance level' set was $p \leq 0.10$ and probability levels of $p \leq 0.15$ are reported in the tables to show any possible effects.

Results

We measured the effects of seven presumptive factors on the establishment and performance of nine weeds of mixed grass prairie, Lostwood NWR, ND. The factors were habitat, fire (burn/unburned, # burns, burn x habitat, time since burn, and season of burn) and grazing (grazed/ungrazed and time since grazing). While the major species (e.g., *B. inermis, P. pratensis, S. occidentalis*) were present at 52-88% of all sites, the minor species (e.g., *E. esula*) were present at as few as 2% of the sites (Table 1.4).

We introduce our results by plotting, for three important species, species response (ubiquity or dominance) vs. number of burns under two treatments (grazed and ungrazed) and four habitats (bottom, north slope, south slope, and hilltop, Tables 1.1 and 1.2). A qualitative evaluation shows little effect of number of burns, little distinction between grazed and ungrazed treatments, and little distinction between habitats. We call the distinction small because the slopes of the lines are slight and the variation around them is large. A more quantitative/detailed examination based on multiple regression is presented below.

Invasion capacity by treatment. Invasion or establishment capacity depends on dispersal and local establishment. It was indexed by frequency, the probability of finding the plant at a random point in each treatment (Table 1.2). The following paragraphs consider seven significant influents. A capital letter following a species name indicates the significance of a factor (the factor discussed) on the species (e.g., A: $p \leq 0.0001$, B:

p≤0.01, C: p≤0.05, D: p≤0.1, E: p≤0.15; see also Tables 2.1-2.3 for significance values). The codes listed here apply to the remainder of this paper.

Habitat influenced establishment in eight of nine weeds. Since the sites were coded by soil water (bottom=1, north=2, hilltop=3, south=4,), a negative coefficient indicates decreasing success uphill (Table 1.2). *Populus tremuloides, E. esula, M. officinalis*, and *T. dubius* were more likely to establish on drier than moister sites (Table 1.2). Except for *P. tremuloides*, the plants are establishing best on segments of the water gradient with which they are normally associated.

The frequency of a perennial is likely to rise with **number of burns** because each fire provides new low competition 'safe-sites' and perennials, which are unlikely to be destroyed by fire, will accumulate across fires. While annuals/biennials may establish more easily after a fire, their lack of perennating organs providing a between-fire bridge may prevent successive accumulation. Perennial *P. tremuloides* increased slightly with number of burns (E, Table 1.2). The other perennials showed neither positive nor negative responses. *Cirsium arvense* (A) and *T. dubius* (A) were negatively influenced by fire (Table 1.2). This may be due to destruction of seed which normally provides their bridge to the future.

The response of several plants to fire differed among habitats (**Ht x Burn**). Fire damage increased upslope for *B. inermis, S. occidentalis,* and *P. tremuloides*. Despite the interaction suggested for *C. arvense* and *M. officinalis* (Table 1.2), it was not substantiated in habitat by habitat analyses (Table 1.3).

Season-of-burn (coded as: no-burn=0, spring=1, summer=2, fall=3) did not affect the frequency of any plant. Thus, we saw no measurable differences among seasons in related seed/vegetative dispersal or seed bed quality.

The **years since the last burn (YSB)** might have positive or negative effects on ubiquity. YSB should increase weed ubiquity (frequency) if the plant is nearly

exterminated by fire, but it recovers through time by local seeding/suckering. For example, *B. inermis* (E, Table 1.2) increased. On the other hand, the ubiquity of 'fire plants' that establish after fire and are competitively eliminated through time will decline. For example, *C. arvense* (A) and *P. pratensis* (A) decreased (Table 1.2). The frequency of most plants was not correlated with YSB.

Grazing might have positive effects on ubiquity [if the grazer disperses or plants seeds] and negative effect [if the grazer consumes many seeds or somehow destroys the seedbed]. *Populus tremuloides* (D), *E. commutata* (B), *E. esula* (A), and *M. officinalis* (A) were retarded by the cumululative treatement. *Poa pratensis* (B) benefited (Table 1.2). The results for *P. pratensis* differed in sign (direction) between the analysis of the cumulative treatment and number of burns discussed below (Table 1.2). **The coding of this response is counter-intuitive; a positive sign indicates a decrease.**

Number-of-grazes is similar to cumulative past grazing, but better quantified. Thus, hypotheses for its effects parallel those for cumulative grazing. The positive correlation for *E. commutata* (B), *E. esula* (B), *M. officinalis* (B), and *T. dubius* (B) may be due to digestion-resistant seeds. Seed bed preparation may be positive for *T. dubius* (B) and negative for *P. pratensis* (D, Table 1.2).

Years-since-grazing and **grazing x burn** effects, discovered at Des Lacs, were not found at Lostwood NWR.

Plant performance by treatment. While dispersal/establishment determines ubiquity, a ubiquitous plant can be relatively unimportant or dominant on-site. For example, while a single stemmed biennial (e.g., *T. dubius*) is unlikely to dominate, a rhizomatous perennial (e.g., *B. inermis* or *P. pratensis*) may be localized or dominant depending on resource and competitive conditions on-site. We index the weed's tendency to dominate a site with cover at the sites where the weed does occur (Table 1.2). Because we do not know when the weed established, we have not corrected for the number of years the plant has occupied the site.

Habitat. *Melilotus officinalis* (D) and *E. commutata* (E) are the only plants whose performance (i.e., dominance) differed among **habitats.** *Melilotus officinalis* had a greater tendency to dominate on dry sites (Table 1.2), where competition may have been less, and *E. commutata* did best on wetter sites, perhaps because it overtopped its competitors.

Fire. We expect increasing **number of burns** to bolster performance of perennials whose competitors are more impacted than they are. Two shrubs (*S. occidentalis*, C) and *E. commutata* (A) seem to be examples (Table 1.2). It appears that repeated burning could only benefit a biennial if competitors were being permanently weakened. This may be so for *M. officinalis* (B) and *T. dubius* (D, Table 1.2). Reciprocally, burning might inhibit a biennial if its competitors were bolstered.

A **habitat x fire** interaction was suggested by our multiple regression analysis (Table 1.2), but none was seen when the effect of fire was tested for in separate habitat-by-habitat analyses.

Dominance should increase with the **years since burn** (YSB) if the plant is set back by fire and recovers. This is especially likely for clonal perennials and unlikely for biennials. *Poa pratensis* (A) and *E. commutata* (E) increase with YSB (Table 1.2). A plant that increases with time since burn must be recovering after being weakened by fire. Reciprocally, a plant that decreased would have established after fire and was being squeezed out by competition of the recovering community.

When coding is spring=1, summer=2, fall=3, a negative trend in plant response to **season** of burn implies that summer burns reduce cover more than spring. This effect is seen for *P. pratensis* (A), *S. occidentalis* (C), and *E. commutata* (E). The impact of summer burns is a surprise for cool-season *P. pratensis* since one expects its production to be higher in spring than summer. Summer burns may be most damaging to *S. occidentalis* and *E. commutata* because hotter burns of summer kill more stems.

Grazing. Weed cover would be less/more on **grazed vs. ungrazed** (cumulative) land if grazing weakened/strengthened the plant relative to its competitors, i.e., weakened it more or less than it weakened the competitors. *Poa pratensis* (C) was more dominant and *Bromus inermis* (D) was less dominant on grazed than ungrazed sites. [Coding for this treatment is counter instuitive; a positive sign indicates a decrease.]

Since we doubt that a single grazing treatment has a permanent impact, a more refined test of grazing effects is the regression of weed dominance against **number of grazes**. Two plants, neither responding in the grazed/ungrazed analysis, responded. The increase in *S. occidentalis* (C) may be due to cattle preference for herbs over brush. The increase in *T. dubius* (C) might be due to cow rejection or seed planting (trampling) required in its biennial life cycle.

While we saw no **years-since-graze** or **grazing x burn** effects at Lostwood, both responses were observed at Des Lacs.

Discussion

Overview. We introduced our results by plotting, for three species, species response (ubiquity or dominance) vs. number of burns under two treatments (grazed and ungrazed) and four habitats (bottom, north slope, south slope, and hilltop, Tables 1.1 and 1.2). A qualitative evaluation shows little effect of number of burns, little distinction between grazed and ungrazed treatments, and little distinction between habitats. We call the distinction small because the slopes of the lines are slight and the variation around them is large. A more quantitative/detailed examination based on multiple regression is presented below.

Fire effects. We draw two conclusions, each with sub-conclusions, with respect to fire. While fire has little effect those effects were very significant. That being the case, fire effects are probably stronger than they appear to be and might be better demonstrated if unidentified factors could be stratified out.

The ubiquity (frequency) of eight of nine weeds was affected by fire (# burns and/or Burn x Habitat). *Populus tremuloides* increased with increasing number of burns while *C. arvense* and *T. dubius* decreased. *Bromus inermis* (NST), *S. occidentalis* (ST), *P. tremuloides* (NST), *E. esula* (BNST), *C. arvensis* (BNST), and *M. officinalis* (BNST), i.e., all but *P. pratensis*, *T. dubius*, and *E. commutata,* were significantly reduced by fire in at least some environments (Table 1.3; B=bottom, N=north, S=south, T=top). *Poa pratensis* decreases (A), year-by-year after fire, as if fire favored native plants over the exotic (Table 1.2). *Cirsium arvense* apparently establishes after fire (a fire-dependent species) and decreases year-by-year after establishment (A, Table 1.2).

The performance (cover) of seven of nine species was affected by fire. 1) At occupied sites, woody plants (*S. occidentalis* (C) and *E. commutata* (A)) and biennials (*M.* officinalis (B) and *T. dubius* (C)) increased with number of burns (Table 1.2), perhaps due to stimulation of sprouting. 2) While the burn x habitat interaction showed significant declines for four species (Table 1.2), samples were too few to identify specific

habitat-environmental effects (Table 1.3). 3) Three species were more damaged by late than early summer fire, (i.e., *P. pratensis* (A), *S. occidentalis* (C), and *E. commutata* (E); Table 1.2). The insignificant increase in *C. arvense* with season is consistent with the previous suggestion that it establishes after fire and is out-competed as the native community recovers (Table 1.2). 4) *Poa* pratensis (A) seems to increase, on site, with years-since-burn, perhaps by fire induced sprouting (Table 1.2).

Grazing effects. The ubiquity (frequency) of six of nine species were affected by grazing. Three perennial species (*P. tremuloides*, *E. commutata*, and *E. esula*) are favored by grazing (Gr and # Gr, Table 1.2), probably because competitors are more affected/palatable than they are. *Poa pratensis* is less ubiquitous on ungrazed units (Table 1.2). Biennials (*M. officinalis* and *T. dubius*) increased with grazing (Table 1.2), perhaps because grazing plants their seed and reduces competition.

While the ubiquity of six species seemed to shift with grazing, the results were inconsistent. *Populus tremuloides* (D), *Elaeganus commutata* (B), *Euphorbia esula* (A), and *Melilotus offficinalis* (A) were less under cumulative grazing while *Poa pratensis* (B) increased. Contrary to this an increasing number of burns was associated with a decline in *Poa pratensis* (D) and an increase in *Elaeganus commutata* (B), *Euphorbia esula* (B), *Melilotus offficinalis* (B) and *Tragopogon dubius* (B)). There were no years-since-graze or graze x burn effects on ubiquity.

The performance (cover) of four of seven weeds was influenced by grazing. *Bromus inermis* (D) is less and *P. pratensis* (C) is more productive on grazed than ungrazed sites (Table 1.2), perhaps due to palatability, grazing, or past management. *Symphoricarpos occidentalis* (C) and *T. dubius* (C) both increased with increasing numbers of grazing treatments (Table 1.2), perhaps because grazers eliminate/weaken their competitors.

Unexplained variance. Forces expected to explain much of weed distribution - - environmental type, fire history, and grazing history - - actually explain little of it. While

all have highly significant effects, in total, they explain only 3-9%, depending on the weed considered, of the variance in ubiquity seen (Table 1.2) and only 0-10% of their success (% cover) at sites they occupy (Table 1.3).

The remaining variance must be due to either to factors affecting dispersion or establishment. Consider dispersal. 1) Weeds obviously decline from county roads through pasture roads to untracked rangeland. While all our samples were greater than 10 meters from and less than 400 meters from a road, we have not accounted for variance, within that band, due to distance from a road. Future investigation of weed distribution should include measurement of weed frequency and cover as a function of distance from roads of different magnitudes. 2) While some weeds obviously spread from established patches (e.g., from an old field seeded to brome), we have not accounted for distribution from the nearest stand. Future investigation could include an estimation of proximity to seed sources, measuring the distance and direction of the nearest seed source areas, and correlating infestation with source proximity. 3) Some dispersal may be truly random. This might be especially so for wind dispersed seeds like *P. tremuloides*, *T. dubius*, and *C. arvense*. It might be least so for seeds transported by animals to specific environments—such as those borne in berries (e.g., *S. occidentalis*, *E. commutata*, and *E. esula*) or with digestion resistant seed coats (e.g., *M. officinalis*). While *B. inermis* is neither winged nor animal borne, the fact that it forms a density gradient adjacent to old brome fields suggest that it is wind or small mammal dispersed.

Besides dispersal, establishment/presence is affected by seedbed quality. 1) Beside their influence on dispersal, road shoulders provide 'cultivated' sites with reduced competition. Our stratification with respect to distance from roads surely reduced this effect even more effectively than it reduced the dispersal-from-roads effect. 2) A factor that varied among units (=pastures) without correlation either to fire or grazing could account for unexplained weed distribution. We mention three possibilities. Soils vary (become sandier) from north to south across the moraine/refuge (Rolling and Dhuyvetter 2003, etc). Past management probably/undoubtedly varies since some units were nearer homesteads than others and thus one can imagine residual effects of grazing and fire

management. Small mammals, as burrowers/planters, might vary with soils (or management histories). [While variance in soils and pre-1930 management may be among the most likely sources of unaccounted for variance, we did not test for them in the analysis of our management experiment because subdividing the sample further would have reduced sample sizes excessively. These effects might be investigated by adding measurements of soil quality and management history to regressions of weed presence vs. likely factors.]

Management of major species. While one can deduce effects of management for any of our species from Tables 1.2 and 1.3, we explicitly outline the management implications of fire and grazing treatment for three especially offensive plants.

Recall first, that, while the effects of fire and grazing are often very significant, they explain little of the variance in weed distribution. Thus, the comments below should be applied not in planning management of these weeds, but in projecting what will be the effect on these weeds of fire/grazing treatments/management applied for other reasons. We have no evidence that any of the weeds in this study can be controlled by fire or grazing alone or in concert. This is contrary to observations from tall grass prairie where fire and grazing can be used to control cool season weeds.

Bromus inermis was little affected by burning or grazing. The ubiquity (frequency) of *B. inermis* was slightly reduced by fire on hilltop habitats (Table 1.3). *Bromus inermis* benefited insignificantly from fire on north slopes (Table 1.3). While grazing apparently does not promote the spread of *B. inermis* (Table 1.2), its cover is less (D) on grazed than ungrazed units (Table 1.2). The fact that cover does not change with number-of-grazes (Table 1.2) may suggest that the 'response' is tied to a confounded soil or historical factor, rather than the grazing itself.

Poa pratensis seems to have been almost unaffected by fire and slightly reduced by grazing. The ubiquity (frequency) of *P. pratensis* is unaffected by fire history (number-of-burns, Table 1.2) and it may decrease after fire (years since burn, Table 1.2).

Its performance (cover) is also unaffected by fire history (#burns and #burns x habitat, Table 1.2). Its cover is most reduced by late season burns (Table 1.2). It tends to increase after fire (YSB, Table 1.2) as if it is complementarily benefited by fire. The fact that the ubiquity of *P. pratensis* decreases with number of grazing treatments (Table 1.2) seems inconsistent with its being more common (B) on grazed than ungrazed sites (Table 1.2).

Our data suggest that *S. occidentalis* is slightly retarded by fire and slightly encouraged by grazing. *Symphoricarpos occidentalis* ubiquity (frequency) is reduced by fire on south facing and hilltop sites (Table 1.3). Its cover is increased (C, Table 1.2), perhaps due to resprouting within clones. *Symphoricarpos occidentalis* is more damaged (C) by late summer than spring fire (Table 1.2). While its ubiquity (frequency) is unaffected by grazing (Table 1.2), its cover seems to increase with increasing number of grazing treatments (C) (Table 1.2).

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Table 1.1. **Fire (# burns) and grazing (ungrazed vs. lightly grazed) history** (1972-2002) of 22 management units (in 2001) and 27 management units (in 2002) at **Lostwood National Wildlife Refuge**, Kenmare ND. Data collected were used to determine invasiveness (frequency) and success (= dominance = cover) of nine weeds in four environments (bottoms, n-slopes, hilltops, s-slopes), fire treatment (burn vs. no burn, # burns, time since burn, season of burn) grazing treatment (graze vs. no graze, # grazes and time since grazing), and interaction between grazing and number of burns (See Table 2).

# Burns	0	1	2	3	4	5	6
			2001 Sampled				
Ungrazed	2		2	2	3	1	
Grazed	3		1	1	3	3	1
			2002 Sampled				
Ungrazed	1	2	1	3	3	2	
Grazed	2	3	1	1	3	4	1
			Total sampled				
Ungrazed	3	2	3	5	6	3	0
Grazed	5	3	2	2	6	7	1

Table 1.2. **Invasiveness (frequency) and success= (dominance=cover) of nine weeds** in four environments (bottoms, n-slopes, hilltops, s-slopes), fire treatment (# burns, time since burn, season of burn) and grazing treatment (# grazes and time since grazing) on **Lostwood National Wildlife Refuge**. Responses are indexed with coefficients of a multiple regression of each species against the seven environmental variables. The significance of each response is indicated by a probability class, A≤0.001, B≤0.01, C≤0.05, D≤0.10, E≤0.15, n (or--) = not significant.

Factor[1]	Adjr[2]	C	Ht	#Brn[3]	B x Ht[3,4]	Seasn B	Yr.S.B	Gr	#Gr[3]
Invasiveness (frequency)									
Brin[2]	0.06	0.5A	-0.05C	--	-0.01B	--	0.01E	--	--
Popr	0.06	1.0A	-0.06A	--	--	--	-0.02A	-0.10B	-0.02D
Syoc	0.06	0.9A	-0.07A	--	-0.01D	--	--	--	--
Potr	0.05	-0.0n	0.04A	0.01E	-0.01B	--	--	0.01D	--
Elco	0.01	0.2A	--	--	--	--	--	0.09B	0.03B
Eues	0.03	0.0n	0.02B	--	-0.01B	--	--	0.04A	0.01B
Ciar	0.09	0.3A	-0.06A	-0.05A	0.01C	--	-0.01A	--	--
Meof	0.03	-0.0n	0.02B	--	-0.01B	--	--	0.04A	0.01B
Trdu	0.05	0.0C	0.02A	-0.01A	--	--	--	--	0.01B
Dominance (cover)									
Brin[2]	0.02	14.8A	--	--	-0.35C	--	--	1.71D	--
Popr	0.05	11.2A	--	--	--	-5.54A	5.28A	-1.11C	--
Syoc	0.05	11.6A	--	0.84C	-0.47A	-0.29C	--	--	0.54C
Potr	0.00	-4.2n	3.04n	1.81n	-0.99n	-6.35n	7.91n	4.80n	1.18n
Elco	0.05	3.7A	-0.44E	0.55A	--	-1.3E	1.15E	--	--
Eues	0.00	-28.2n	10.49n	11.47n	-2.52n	-7.24n	8.96n	-13.18n	--
Ciar	0.00	1.01n	0.37n	0.21n	-0.14E	0.49n	-0.52n	0.25n	--
Meof	0.10	-3.01n	1.44D	1.98B	-0.67C	--	--	--	--
Trdu	0.05	0.42A	--	0.04C	--	--	--	--	0.03C

[1] Factors tested (column headings) are adjusted r^2 (Adj r^2), intercept (C), habitat (Ht; drier sites having a higher code number), number of burns (#Brn), number of burns by habitat interaction (B x Ht), season of burn (Seasn B; later seasons having a higher code number), years since burning (Yr.S.B.), grazing (Gr; + (grazed) or – (ungrazed)), and number of grazing events (#Gr).

[2] Weed species include grasses (*Bromus inermis* (BRIN) and *Poa pratensis* (POPR)), shrubs/trees (*Symphoricarpos occidentalis* (SYOC), *Populus tremuloides* (POTR), and *Elaeagnus commutata* (ELCO)), perennial forbs (*Euphorbia esula* (EUES) and *Cirsium arvense* (CIAR)) and biennial forbs (*Melilotus officinalis* (MEOF) and *Tragopogon dubius* (TRDU)).

[3] Interpretation of four columns is less than straightforward. The sign of the cumulative burns and grazing is counterintuitive; a positive coefficient indicates a decline and vice versa. The sign of the interaction terms (e.g., burn x ht and grazing x fire) is meaningless; a significant interaction is examined by testing the components eparately, e.g., effect of fire in each habitat and effect of grazing on burned and unburned sites.

[4] The presence of slopes and signs for effects of the habitat x burning treatment have little meaning; the effect of this interaction is seen in the table of interactions (Table 1.3).

Table 1.3. **Comparison of burn (# burns) effect between four environments** (bottom, North-slope, hilltop, and South-slope) on **Lostwood National Wildlife Refuge**. Invasion (frequency) and establishment (cover) capacity of nine species are recorded. The burn coefficient found in multiple regressions run for each weed species and environment is shown. The significance of each response is indicated by a probability class, A≤ 0.001, B≤0.01, C≤0.05, D≤0.10, E≤0.15, n (or--) = not significant.

Environment	Bottom	North slope	South slope	Hilltop
Fire x invasability (frequency)				
BRIN[1]	--	-0.029E	-0.054C	-0.056B
SYOC	--	--	-0.006n	-0.049C
POTR	--	-0.015C	-0.012E	-0.037A
CIAR	-0.014C	-0.014D	-0.026C	-0.018C
MEOF	--	--	--	--
Fire x success (cover)				
BRIN	--	0.351n	--	--
SYOC	--	--	--	--
MEOF	--	--	--	--

[1]Weeds are *Bromus inermis* (BRIN), *Symphoricarpos occidentalis* (SYOC), *Populus tremuloides* (POTR), *Cirsium arvense* (CIAR), and *Melilotus officinalis* (MEOF).

Table 1.4. **Percent of plots in which each of the nine weed species appeared (i.e., cover > 0)**. Data are presented as the percent across all sites and also the percent within each habitat (bottom, North-slope, South-slope, and hilltop) on **Lostwood National Wildlife Refuge**.

	ENVIRONMENT				
	All habitats n=500	Bottom n=125	North slope n=125	South slope n=125	Hilltop n=125
BRIN[1]	52	65	65	42	38
POPR	88	87	94	92	81
SYOC	81	82	91	88	65
POTR	4	2	6	3	6
ELCO	41	29	66	27	42
EUES	2	1	2	2	3
CIAR	32	44	30	29	25
MEOF	12	7	5	19	16
TRDU	29	18	26	39	32

[1] Weeds are *Bromus inermis* (BRIN), *Poa pratensis* (POPR), *Symphoricarpos occidentalis* (SYOC), *Populus tremuloides* (POTR), *Elaeagnus commutata* (ELCO), *Euphorbia esula* (EUES), *Cirsium arvense* (CIAR), *Melilotus officinalis* (MEOF), and *Tragopogon dubius* (TRDU).
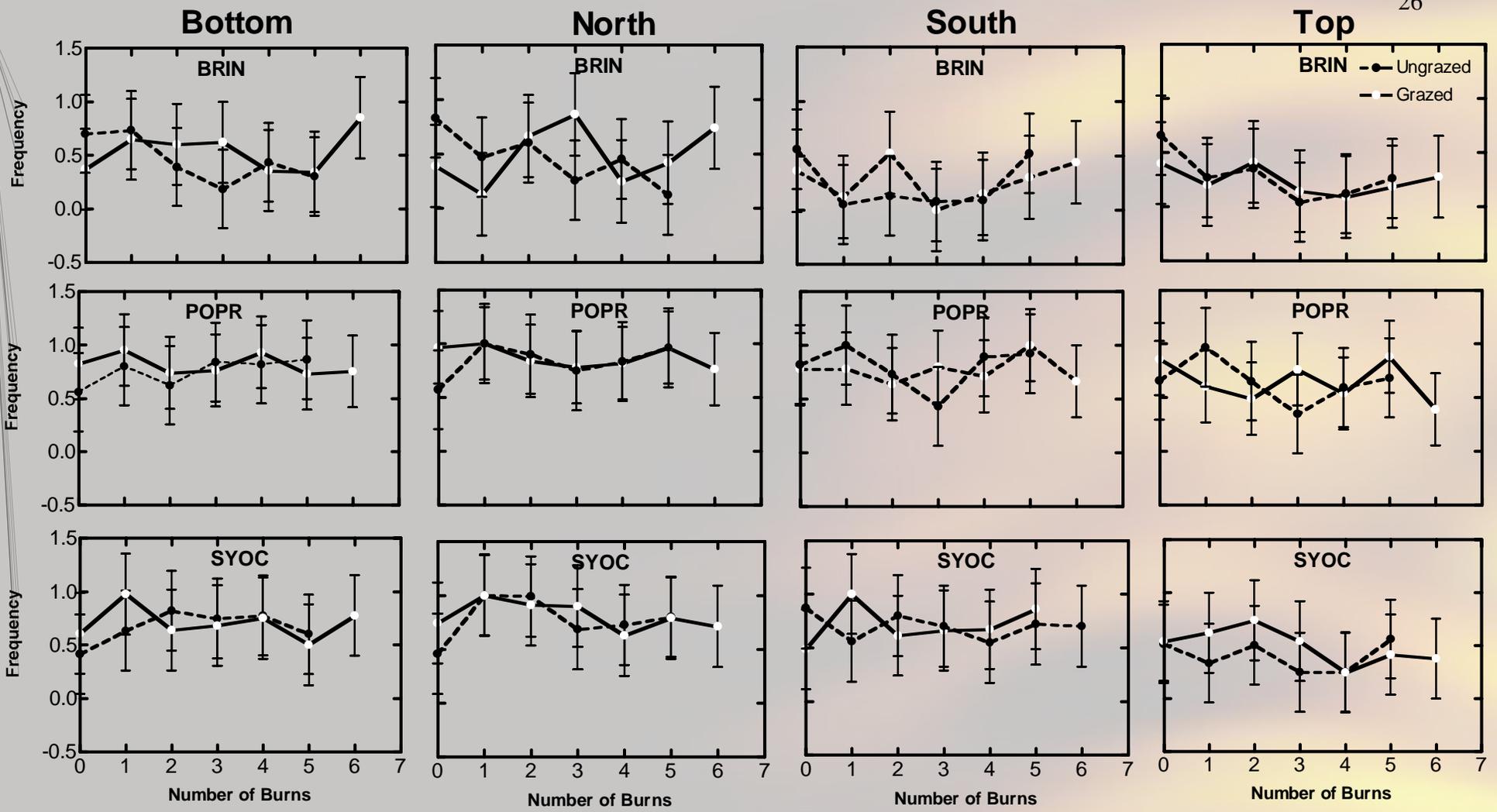
Figure 1.1. Ubiquity (frequency) of three invasive species of mixed grass prairie (*Bromus inermis* (BRIN), *Poa pratensis* (POPR), *Symphoricarpos occidentalis* (SYOC)) as influenced by habitat (bottom, North slope, South slope, hilltop), number of burns, and grazing (grazed (open symbol) vs. ungrazed (closed symbol).
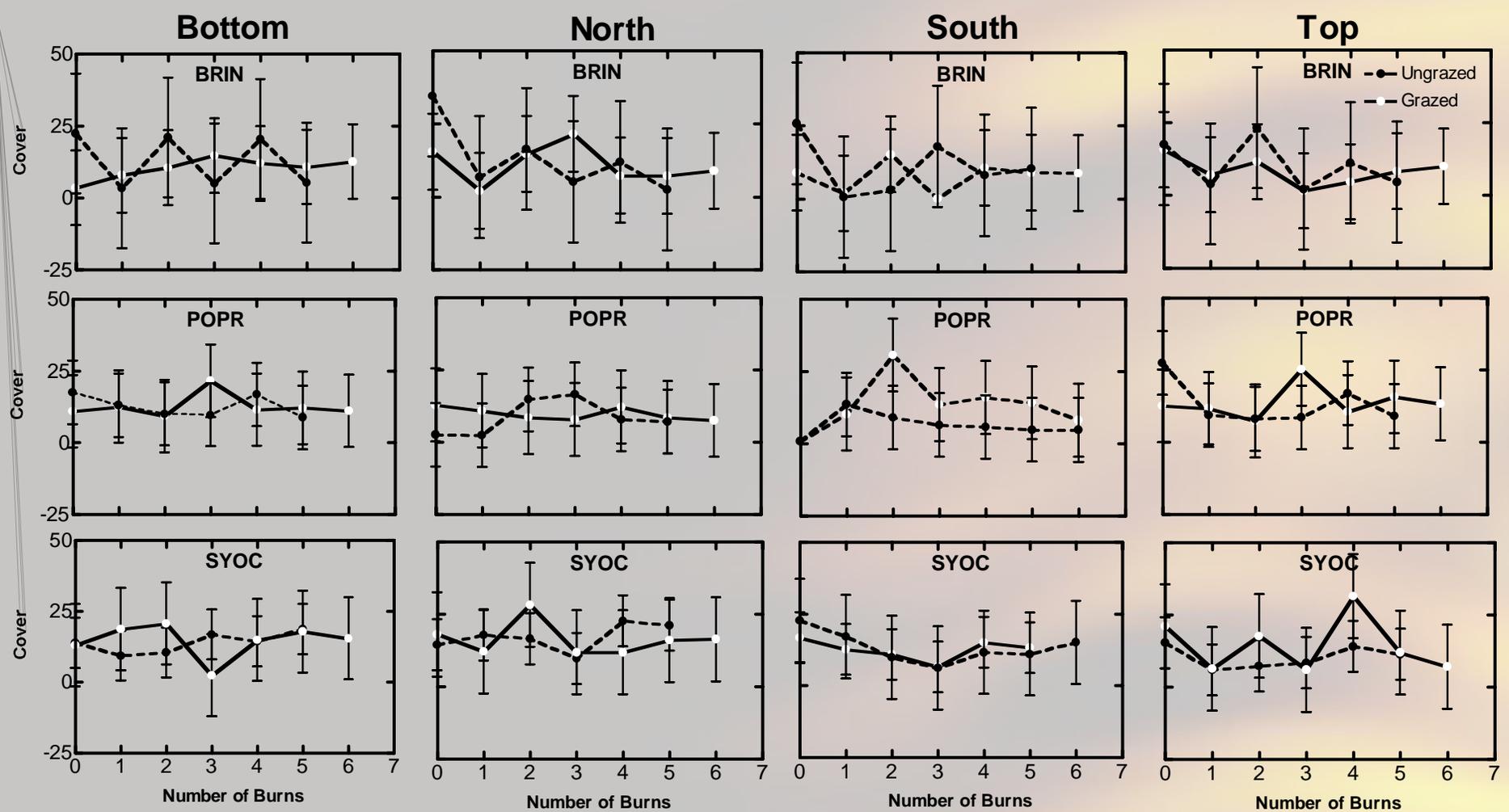
Figure 1.2. Success (% cover) of three invasive species of mixed grass prairie (*Bromus inermis* (BRIN), *Poa pratensis* (POPR), *Symphoricarpos occidentalis* (SYOC)) as influenced by habitat (bottom, North slope, South slope, hilltop), number of burns, and grazing (grazed (open symbol) vs. ungrazed (closed symbol).

CHAPTER 2

Effect of fire and grazing on invasive species
in northern mixed grass prairie on Des Lacs NWR, N Dakota

Abstract

To measure the effects of fire and grazing on weeds in northern mixed grass prairie, we analyzed a management experiment conducted at Des Lacs National Wildlife Refuge (NWR) in northwestern North Dakota. The experiment included six fire treatment (0-6 prescribed burns) and two grazing treatments (none and light) in a replicated factorial design. The effects, on nine weed species, of habitat (bottoms, north slopes, south slopes, and hilltops), fire (burn vs. no burn, number of burns, season of burn, years since burn), and grazing (none of light, number of grazes) were examined with multiple regression. The weeds include exotic grasses (*Bromus inermis* Leyss. and *Poa pratensis* L.), woody natives (*Symphoricarpos occidentalis* Hook., *Elaeagnus commutata* Bernh., *Populus tremuloides* Michx.), perennial exotic herbs (*Euphorbia esula* L. and *Cirsium arvense* L.), and biennial exotic herbs (*Melilotus officinalis* L. and *Tragopogon dubius* L.).

While there were many significant (p=0.00001-0.1), the trends were always weak. Thus, we conclude that, while neither fire nor grazing successfully control weeds in the mixed grass prairie, the manager will use our data to estimate the effects, on weed presence, of fire and grazing applied for other purposes.

Key words. Weed invasion, weed control, exotics, fire, grazing, mixed grass prairie, *Bromus inermis*, *Poa pratensis*, *Symphoricarpos occidentalis*, *Elaeagnus commutata*, *Populus tremuloides*, *Euphorbia esula*, *Cirsium arvense*, *Melilotus officinalis*, and *Tragopogon dubius*, Des Lacs NWR, North Dakota.

Introduction

Northern mixed grass prairie is threatened by both exotic and native invasive species (Samson and Knopf 1996, Larson et al. 2001). Native shrubs (e.g., *Symporicarpos occidentalis*) and exotic grasses (e.g., *Bromus inermis* (Blankespoor 1987, Willson 1992) and *Poa pratensis*) are primary threats. Less threatening invaders include other woody natives (e.g., *Elaeagnus commutata*), exotic perennial forbs (*Euphorbia esula* and *Cirsium arvense*) and exotic biennial forbs (*Melilotus officinalis* and *Tragopogon dubius*). We consider fire and grazing as management tools.

Woody shrubs are increasing on National Wildlife Refuges (NWRs) and other rangelands of the northern mixed grass prairie (Weaver and Plaggemeyer 2004). Two environmental changes that may be responsible are fire suppression and reduction in cattle/buffalo grazing. Fire reduction should favor shrubs because they are retarded by fire. Simultaneously, cattle grazing might either favor shrubs (by reducing grass/forb competition) or reduce them (by trampling). Thus, we hypothesize that reintroduction of fire will reduce shrub presence/dominance and that light grazing will have no effect on shrub presence/dominance.

Exotics, especially *B. inermis* (Looman 1969, Wilson 1989, Romo et al. 1990, Blankespoor and Larson 1994, Willson and Stubbendieck 2000) and *P. pratensis*, are also increasing. Exotic grasses might also be managed using prescribed fire tools (Old 1969, Sather 1988). Spring burning controls these grasses in tall grass prairie (Willson 1992, Willson and Stubbendieck 2000), because spring burning damages the cool season invaders before warm season dominants become active (Grilz and Romo 1994). Efforts by managers to transfer this practice from tall grass to mixed grass prairie are likely to fail, because weeds and natives of northern mixed grass prairie have the same phenology (Willson and Stubbendieck 2000). That is, while a spring fire may damage cool season exotics, selection against them will be less than in tall grass prairie, because cool season natives will also be damaged, exposing new niches (Curtis and Partch 1948, Hobbs and Huenneke 1992, Masters and Sheley 2001, Shay et al. 2001). Fire may actually favor the rhizomatous exotics (Kirsch 1974, Blankespoor 1987, Grilz and Romo 1994, Willson and Stubbendieck

1996) because rhizomatous plants are generally less susceptible than the bunch-grass natives. Thus, we hypothesize that fire will have neutral to positive effects on exotic grasses.

Exotic herbs might also be managed with grazing. Grazing should select against exotics if they are more palatable or if it is applied in a season when they are more palatable/actively growing. Since it is believed that spring palatability declines from *B. inermis* to *P. pratensis* to natives and fall palatability declines from *P. pratensis* to natives to *B. inermis*, we expect spring grazing to select against *B. inermis* and fall grazing to select against *P. pratensis*. Considering these two factors, we hypothesize that spring grazing will have neutral to negative effects on exotic grasses.

We used an outstanding [adaptive] management experiment to test our hypotheses. Twenty management units of Des Lacs NWR have been differentially treated, with good records, for nearly 25 years. (The burning has been done since 1980s, and frequently for last 10 years). To yield a replicated factorial experiment with six burning (0, 1,…, 6 burns) and two grazing treatments (Table 2.1). We sampled these to measure their influence on weed presence, i.e., ubiquity (frequency) and cover. Weed responses were measured separately on four increasingly xeric habitats (bottoms (B), north slopes (N), hilltops (T), and south slopes (S)) of each unit to facilitate extrapolation to other sites and other regions.

Methods

Experimental design/approach. The division of the refuge into management units with different well-recorded fire and grazing histories provided a factorial management experiment suitable for measuring the effect of fire and grazing on unwanted shrubs/trees and exotic herbs of mixed grass prairie. The management units included 23 similar units (e.g., vegetation, soil type) that differed primarily in number of prescribed burns (0-6) and the level of grazing (grazed or ungrazed). Treatments spanned the range of burn number but were not completely balanced (Table 2.1). The burns were typically conducted either during April-May (spring burn) or August-October (fall burn). Grazing was on a three-year rotation with two passes per year.

The rolling topography of the refuge allowed us to nest habitat types (bottoms, north-slopes, hilltops, and south-slopes) in each treatment unit and therefore both to compare treatment effects on landscape facets of the refuge and to extrapolate our results to other areas, i.e., from south-slopes to drier areas in the region (e.g., eastern MT) and from north-slopes to moister areas in the region (e.g., central ND).

Study area. Des Lacs NWR encompasses approximately 8,100 ha along 45 km of the Des Lacs River in Ward and Burke Counties, ND. The land surface, in general, is a gently rolling plain. Topographic features are typical of ground moraine, including flat to rolling terrain, small mounds, shallow depressions, and marshy areas. The southerly flowing Des Lacs River occupies a deep valley in the Drift Plain that is 1.6 km wide at maximum. The refuge includes most of the coulees and steep slopes that drain into seven major and three minor water impoundments totaling about 2,429 ha of marsh and water.

2002 had near-average precipitation, that is, with 45.4 annual cm with 43% falling during March-June. 2003 had somewhat wetter conditions, that is, with 53.8 cm with 45% falling during March-June.

Des Lacs NWR's grassy matrix is typical of the mixed grass prairie ecosystem of the northern Great Plains (Kuchler 1964). Dominant indigenous species are needlegrasses (*Stipa* spp.) and wheatgrasses (*Agropyron* spp.). Exotic grasses (primarily *B. inermis*, *P. pratensis*) and woody natives (primarily *S. occidentalis*, *E. commutata*, and *P. tremuloides*) are invading strongly.

Beginning in the 1850s, northwestern North Dakota was subjected to extensive ranching, intensive cultivation, some coal mining. Prairie regulators were modified; fire suppression was initiated and grazing [probably] increased and then ceased, with creation of the refuges. Grazing and agricultural activities – except for cooperative farming and haying on limited previously-cropped areas – ceased on Des Lacs NWR after its establishment in the 1930s. The effects of long-term fire and grazing suppression are seen in the landscape today, especially in the spread of woody vegetation and exotic grasses *Bromus inermis* and *Poa pratensis*. The goal of NWRs in North Dakota -- to preserve and enhance the natural

integrity and diversity of habitat and sanctuary for migratory birds and other wildlife (16 U.S.C. § 715d; Migratory Bird Conservation Act) species of the northern Great Plains -- is challenged by a land management history that has supported this invasion.

Procedures. To compare weed establishment and success in four habitats, six fire treatments, and two grazing treatments, we sampled two to five random points in each habitat (B, N, T, S) across 23 management units (in 2002 and 2003). Data were collected from 36 sites in 2002 and 240 sites in 2003 on Des Lacs NWR.

Twelve random points were located in each management unit with a random point sampling tool in ArcView. Each site was located on-the-ground with a GPS instrument (Trimble Pro-X or Garmin eTrex Vista). Upon visiting a site, its aspect and habitat type were determined. The sites chosen ranged in habitat type from bottoms (13%), north to east slopes (26%), south to west slopes (15%), and hilltops or high flat areas (46%). Roadsides and remote areas were stratified out.

The vegetation at each site was sampled along a 20-m transect centered on the random point, running along the contour, and with constant aspect. Ten 1x1 m quadrats, located on alternate meters of the transect, were observed for presence and cover. Cover was ocularly measured to the nearest percent. Supplemental characterization of the vegetation was made by the method of Grant et al. (2004); the cover of regional 'community types' was recorded in a 10 cm x 20 m belt transect centered on the random point and running along one side of the quadrats.

We investigated/measured the success of nine invasive species. We defined invasive species as non-native or native species that can potentially dominate an area, eventually replacing native grasses and forbs. We focused on two exotic perennial clonal grasses [smooth brome (*Bromus inermis* Leyss.) and Kentucky bluegrass (*Poa pratensis* L.)]; three native woody species that increase in the absence of fire: [shrubby western snowberry (*Symphoricarpos occidentalis* Hook.) and silverberry (*Elaeagnus commutata* Bernh. ex Rydb.) and arborescent quaking aspen (*Populus tremuloides* Michx.)]; two noxious perennial clonal forbs: [leafy spurge (*Euphorbia esula* L.) and Canada thistle (*Cirsium arvense* L.)]; and two exotic biennial forbs: [yellow sweet clover (*Melilotus officinalis* L.)

and goatsbeard (*Tragopogon dubius* L.)]. The first three were chosen for their immediate management concern and the remaining six were selected as contrasting life forms.

Two indices of success were used. First, the invasiveness of a weed at a site was indexed with frequency, the percent of the 10 quadrats sampled that were occupied by the weed. That is, an invasive weed has a high frequency (number of occupied plots/10) and a weak invader has a low frequency. Second, the capacity of a weed to dominate a site it invaded is indexed by its average cover in occupied quadrats at the site, that is average dominance was only measured across quadrats in which the plant established.   To illustrate, a biennial weed (e.g., *Tragopogon dubius*) can have a high frequency and a low cover, while a clonal grass (e.g., *Bromus inermis*) whether it has a high or low frequency often has a high cover.

Statistical analysis. The number of burns for a management area was used to scale sampled units along a gradient from 0 (no fire in more than 80 years) to 6 (many burns, the last burn within 1-2 years). Vegetation data were analyzed using multiple regression analysis to quantify the relationships between invasive weed presence (frequency and cover) and treatment (habitat, fire, and grazing). Habitat had four topographic facets (bottom, north, south, and top). Fire had several facets (+/-, number of burns, season of burn, years since burn) and grazing had three facets (+/-, number of grazes, years since last graze). Statistical models were separated by habitat and tested for effects of the above listed factors. While many were tested, only two interactions, burn x habitat and burn x graze, were significant in the analysis. Percent cover values were untransformed and assumptions of normality could be assumed based on the central limit theorem because sample sizes were large enough (e.g., n = 2,760). Some analyses were pooled by year, grazing and no-grazing, or include other factors as noted. Because effects of fire, grazing, and habitat were less than expected, the 'statistical significance level' set was $p \leq 0.10$ and probability levels of $p \leq 0.15$ are reported in the tables to show any possible effects.

Results

We measured the effects of ten presumptive factors on the establishment and performance of nine weeds of mixed grass prairie, Des Lacs NWR in northwestern North Dakota. The factors were habitat, fire (burned/unburned, # burns, burn x habitat, time-since-burn, and season of burn) and grazing (grazed/ungrazed, # grazes, years-since-grazing, and grazing x burning). While the major species (e.g., *P. pratensis, B. inermis, S. occidentalis*) were present at 72-93% of the sites, the minor species (e.g., *P. tremuloides*) were present at as few as 1% of all sites (Table 2.5).

We introduce the data by plotting, for three important species, species response (ubiquity or dominance) vs. number of burns under two treatments (grazed and ungrazed) and four habitats (bottom, north slope, south slope, and hilltop, Tables 2.1 and 2.2). A qualitative evaluation shows little effect of number of burns, little distinction between grazed and ungrazed treatments, and little distinction between habitats. We call the distinction small because the slopes of the lines are slight and the variation around them is large. A more quantitative/ detailed examination based on multiple regression is presented below.

Invasion or establishment capacity. Invasion or establishment capacity depends on dispersal and local establishment. It was indexed by frequency, the probability of finding the plant at a random point in each treatment. The following paragraphs consider ten significant influents. A capital letter following a species name indicates the significance of a factor (the factor discussed) on the species (e.g., A: $p \leq 0.0001$, B: $p \leq 0.01$, C: $p \leq 0.05$, D: $p \leq 0.1$, E: $p \leq 0.15$; see also Tables 2.1-2.3 for significance values). The codes listed here apply to the remainder of this paper. A '–OL' following a 'probability letter' indicates that the response is opposite that observed at Lostwood. Such reversals are summarized in Table 3.1. Lostwood and Des Lacs NWR observations are compared for each factor. They are inconsistent if the signs of the coefficients are opposite or if one has a coefficient and the other has none. They are called consistent if their signs are alike or if there is no coefficient for either. To highlight the consistency/non-consistency between refuges within a type we specify the number of cases of each, i.e., # where consistent with presence (p) and # where

consistent by mutual absence (a), abbreviated (# present, # absent). The cases consistent by absence are obviously of less interest.

Habitat influenced establishment in four of nine weeds. Since the sites were coded by soil water (bottom=1, north=2, south=3, hilltop=4), a negative coefficient indicates decreasing success uphill (Tables 2.2 and 2.3). *Cirsium arvense* (C) had decreasing success uphill. *Bromus inermis* (C-OL), *P. pratensis* (C-OL), and *M. officinalis* (C) had increasing success on drier uphill sites (Table 2.2). To compare, at Lostwood NWR, *B. inermis* (C), *P. pratensis* (A), *S. occidentalis* (A), and *C. arvense* (A) decreased uphill; *P. tremuloides* (A), *E.* esula (B), *M. officinalis* (B), and *T. dubius* (A), increased uphill (See Chapter 1). The signs of the results are consistent in three (2 present, 1 absent) of nine cases.

If a single burn had a permanent effect, some species might respond to **burn/no burn**; this seems improbable, because if there were such a single burn force, it would have been triggered long ago in a wild prairie fire. Despite the seeming improbability, the frequency/ubiquity of two species (*P. pratensis* (C) and *S. occidentalis* (A)) was higher (indicated by the negative sign) on burned than unburned sites. *Tragopogon dubius* (A) frequency was decreased by fire. To compare, since single burns had no significant effect at Lostwood NWR, the signs of the results are consistent in six (0 present, 6 absent) of nine cases.

We expected the **number of burns** to have opposite effects on the frequency of perennials and annuals/biennials. The frequency of a perennial should rise with number of burns, because each fire provides new low competition 'safe-sites'. Thus perennials -- which are unlikely to be destroyed by fire -- will accumulate across fires. Trees and shrubs were unaffected at Des Lacs NWR. Two grasses, *B. inermis* (A) and *P. pratensis* (C) increased with number of burns, perhaps due to strong rhizomes. Two perennial forbs, *E. esula* (B) and *C. arvense* (D) decreased with number of burns, despite strong rhizome reserves. While -- due to reduced competition -- annuals/biennials might establish more easily after a fire, their lack of perrenating organs to provide a between-fire bridge is expected to prevent repeated increase. Both biennials were unaffected by fire. For comparison, we review plant responses at Lostwood NWR. Perennial *P. tremuloides* increased slightly with number of burns (E, Table 1.2) and *Cirsium arvense* decreased (A).

The other perennials showed neither positive nor negative responses. The biennial *T. dubius* was negatively influenced by fire (Table 1.2). Thus the signs of the the results are consistent for four (1 present, 3 absent) of nine weeds. Explanatory hypotheses need improvement.

A ***habitat x burn interaction*** takes us to table 2.3. Damage increased uphill for one rhizomatous grass *Poa pratensis* (D) and one woody (*Populus* tremuloides (B) (Table 2.3). While the interaction was significant (Table 2.2) for *Poa pratensis* (D), *C. arvense* (E), and M *officinalis* (C), the habitat-by-habitat analysis did not substantiate them (Table 2.3). Three species at Lostwood NWR had a burn x habitat interaction (with *Bromus inermis* (B) and *Symphoricarpos* occidentalis (D) being increasingly affected uphill and *Cirsium* arvense (C) trending so, Table 1.3. Using table 2.2 (not 2.3), the Lostwood/DesLacs patterns are consistent in four (2 present, 2 absent) of nine weeds.

Season-of-burn (coded as: no-burn=0, spring=1, summer=2, fall=3) did not affect the frequency of any plant at either Des Lacs or Lostwood NWR. Thus, we saw no measurable variation among seasons in factors that might affect establishment, i.e., seed/vegetative dispersal or seed bed quality. And consistency was complete.

The ***years since the last burn*** (YSB) might have positive or negative effects on ubiquity. First, YSB should increase weed ubiquity (frequency) if the plant is nearly exterminated by fire (i.e., is not found), but it recovers through time by local seeding/suckering. *Tragopogon dubius* (A) increased at Des Lacs NWR, while *B. inermis* (E, Table 1.2) increased at Lostwood NWR. On the other hand, the ubiquity of 'fire plants' that establish after fire and are competitively eliminated through time will decline. For example, *S. occidentalis* (A) and *E. esula* (D) decreased at Des Lacs NWR (Table 2.2). At Lostwood NWR, *P. pratensis (A) and C. arvensis (A)* decreased (Table 1.2). Results are consistent for only three (0 present, 3 absent) of nine weeds.

Weed response at Des Lacs NWR was measured relative to four aspects of grazing.

1) **Cumulative grazing** might have positive effects (indicated by a minus sign!!) on ubiquity if the grazer disperses or plants seeds; no mechanism for negative effects is apparent. Two forbs (*E. esula* (C) and *C. arvense* (D)) were increased by all levels of

grazing (Table 2.2). At Lostwood NWR, one species increased with grazing and four species decreased (Table 1.2). Thus, signs of the results are consistent for three (0 present, 3 absent) of nine weeds.

2) **Number of grazes** is a better defined independent variable. *Bromus inermis* (B) and *T. dubius* (B) increased with increasing number of grazes while *C. arvense* (E) decreased (Table 2.2). At Lostwood NWR, *E. commutata* (B), *E. esula* (B), *M. officinalis* (B), and *T. dubius* (B) increased with number of burns, while *P. pratensis* (D) decreased (Table 1.2). Thus signs of the results are consistent for three (1present, 2 absent) of nine weeds.

3) A significant positive response to **years since grazing** was observed for *B. inermis* (C) and *C. arvense* (B), while *S. occidentalis* (B), *E. commutata* (C), *E. esula* (C), and *M. officinalis* (E) all declined (Table 2.2). At Lostwood NWR, no species responded to years-since-grazing (Table 1.2), so results are consistent for three (0 present, 3 absent) of nine species.

4) **Grazing and burning interact** when fire has different effects on ungrazed and grazed sites (Table 2.4). *Bromus inermis* (A), *P. tremuloides* (A), and C. arvense* (A) are more damaged by fire on ungrazed sites, as if higher fuel loads bring better control. *Melilotus officinalis* is slightly more damaged when fire occurs on ungrazed sites, as if excess disturbance inhibits establishment. Fire effects are insignificant for *P. pratensis and S. occidentalis*, perhaps due to insufficient sample size. Because no Lostwood weeds responded to the grazing x burning interaction, signs of the results were consistent for three (3 absent) of nine weeds. (Or setting the *S. occidentalis* and *P. tremuloides* effects to zero on the basis of Table 2.4, five (2 present and 3 absent.)

Plant performance by treatment. While dispersal/establishment determines ubiquity, a ubiquitous plant can be relatively unimportant or dominant on-site. For example, while a single stemmed biennial (e.g., *Tragopogon dubius*) is unlikely to dominate, a rhizomatous perennial (e.g., *B. inermis* or *P. pratensis*) may be localized or dominant depending on resource and competitive conditions on-site. We index the weed's tendency to dominate a site with cover at the sites where the weed does occur. Because we do not know when the weed established, we have not corrected for the number of years the plant has occupied the site, a factor of obvious import.

Poa pratensis (A) was the only plant whose performance differed among Des Lacs NWR **habitats.** It had a greater tendency to dominate on dry sites (A, Table 2.2) where competition may have been less. At Lostwood, *M. officinalis* (D) responded positively [also increasing uphill] and *E. commutata* (E) responded negatively. Thus, the signs of the responses of six (3 present, 3 absent) of nine species were consistent between the refuges.

By the **cumulative unburned vs. burned** (1-6 times since 1972) condition, three Des Lacs NWR species were affected. *Euphorbia esula* (A) was apparently damaged (Table 2.2). *Poa pratensis* (C) and *S. occidentalis* (D) benefited as if one fire allows entry (Table 2.2). None of these responses are confirmed by observations of responses to multiple burns, described below. There were no responses to the burn/no burn treatment at Lostwood NWR, thus the responses of six (0 present, 6 absent) of nine species were consistent.

We expect **repeated burning** to bolster performance of perennials whose competitors are more impacted than they are. One perennial grass was damaged; in contrast to its response to burn/no burn, *P. pratensis* (E) declined at Des Lacs NWR (Table 2.2). While none increased at Des Lacs NWR, at Lostwood NWR, two shrubs (*S. occidentalis* (C) and *E. commutata (A)*) increased in proportion to number of burns applied (Table 1.2). It seems that repeated burning could only benefit a biennial if competitors were permanently weakened. At Des Lacs NWR, neither biennial was affected significantly. In contrast, at Lostwood NWR only *M. officinalis* (B) increased, as if it was [they were] damaged less than were its [their] competitors. Thus, the signs of the results were consistent for seven (4 present, 3 absent) of nine species tested.

Dominance should increase with the **years-since-burn** (YSB) if the plant is set back by fire and recovers. This is especially likely for clonal perennials and unlikely for biennials. At Des Lacs NWR, only *P. pratensis* (D) was affected and it increased (Table 2.2). At Lostwood NWR, both *P. pratensis (A)* and *E. commutata (E)* increased with YSB (Table 1.2). A plant that increases with time since burn must be recovering after being weakened by fire. Reciprocally, a plant that decreased would have established after fire and was being squeezed out by competition of the recovering community. We found no species

that decreased significantly at either site. Thus the signs of the responses of seven (3 present, 4 absent) of nine species were consistent.

Burn x habitat seems to have interactions appear for *Bromus inermis* and *Symphoricarpos occidentalis* (Table 2.2), but no trend is seen in the analysis of habitats, one-by-one. At Lostwood NWR, suggested interaction of *Bromus inermis*, *Symphoricarpos occidentalis*, *Cirsium arvense*, and *Melilotus officinalis* (Table 1.2) were also not borne out by separate analysis (Table 1.3). Thus the results are completely consistent; nine of nine species (6 present and 3 absent) were consistent.

When coding is spring=1, summer=2, fall=3, a negative trend in plant response to **season of burn** implies that summer burns reduce cover more than spring. At Des Lacs NWR, damage to one species (*S. occidentalis* (C) fell with season (Table 2.2). At Lostwood NWR, summer burns were most damaging to *P. pratensis (A)*, *S. occidentalis (C)*, and *E. commutata (E)* (Table 1.2). Thus, the responses were consistent for seven (4 present, 3 absent) of nine species.

Grazing. Dominance did not differ between grazed and ungrazed treatment for any species at Des Lacs NWR (Table 2.2). Since, at Lostwood NWR, one species responded positively (*P. pratensis* (C)) and one species responded negatively (*B. inermis* (D); Table 1.2), weed responses were consistent for seven (3 present, 4 absent) of nine species. The coding used gives an increase and a decrease negative and positive signs respectively.

Since we doubt than a single grazing treatment has a permanent impact, a more refined test of grazing effects is the regression of weed dominance against **number of grazes**. At Des Lacs NWR one species *S. occidentalis* (D), increased weakly under grazing (Table 2.2). It also increased at Lostwood NWR, suggesting a general response (Table 1.2). Lostwood (C) NWR's second increaser, *T. dubius* (C), did not increase (Table 1.2). Thus eight of nine species were consistent between the sites: one species increased at both sites, two species increased at Lostwood NWR only, and six (0 present, 6 absent) species were unaffected.

The dominance of a weed might increase/decrease over **years-since-grazing** (YSG), like YSB, if it were rejected/preferred by the grazing animal; the interaction might be direct or mediated through competition. At Des Lacs NWR, *B. inermis* (C) and *C. arvense* (B) increased, while *P. pratensis* (A) decreased (Table 2.2). At Lostwood NWR, no weed's dominance was correlated with years-since-grazing. Thus, the sign of the weed response was consistent in six (0 present, 6 absent) of nine cases.

At Des Lacs NWR the negative **interaction of fire and grazing** on *S. occidentalis* (D) is trivial; fire causes a tiny reduction on grazed sites (C) and a tiny increase (E) on ungrazed sites (Table 2.4). We would have expected the opposite since grazing should reduce fuel load and fire intensity. There were no fire x grazing interactions at Lostwood NWR. Thus the sign agrees in eight of nine cases (0 present, 8 absent).

Discussion

Overview. We introduced the data by plotting, for three species, species response (ubiquity or dominance) vs. number of burns under two treatments (grazed and ungrazed) and four habitats (bottom, north slope, south slope, and hilltop, Figure 2.1 and Figure 2.2). A qualitatitive evaluation showed little effect of number of burns, little distinction between grazed and ungrazed treatments, and little distinction between habitats. We call the distinction small because the slopes of the lines are slight and the variation around them is large. A more quantitative/detailed examination based on multiple regression is presented below.

Fire effects. We draw two conclusions, each with sub-conclusions, with respect to fire effects. While fire has little effect those effects were very significant. That being the case, these effects are probably stronger than they appear to be and might be better demonstrated if unidentified factors were stratified out.

The ubiquity (frequency) of eight of nine weeds was affected by fire (presence/absence, # burns and Burn x Habitat). Three species (*B. inermis* (T), *P. tremuloides* (ST), and *C. arvense* (BNT) were significantly reduced by fire in at least some

environments (Table 2.3; B=bottom, N=north, S=south, T=top). *Symphoricarpos occidentalis* decreases (A) year-by-year after fire, as if fire favored native plants over the exotic (Table 2.2). *Tragopogon dubius* (A) apparently establishes after fire (a fire-dependent species) and increases year-by-year after establishment (Table 2.2). Nineteen of forty-five responses differ (one reversed) from the Lostwood NWR observations.

The performance (cover) of three of nine species was affected by fire. 1) At occupied sites no woody plants, no grasses, and no biennials increased with number of burns (Table 2.2); one perennial forb (*E. esula* (A)) increased in burned vs. unburned areas (Table 2.2), perhaps due to stimulation of sprouting. 2) The significant burn x habitat interaction is due to the fact that *B. inermis* (Table 2.2 and Table 2.4) was especially reduced on hilltops. 3) One species, *S. occidentalis* (C), was more damaged by late than early summer fire. 4) Only one exotic grass (*P. pratensis*, D) increased, on site, with years-since-burn (Table 2.2). Fourteen of forty-five observations differ in sign (one reversed) from those at Lostwood NWR.

Grazing effects. The ubiquity (frequency) of nine of nine species was affected by some aspect of grazing. One perennial species (*B. inermis* (B) and one biennial (*T. dubius* (B)) were favored by grazing (Table 2.2, #Gr), probably because competitors are more affected/palatable than they are. *Euphorbia esula* (C) and *C. arvense* (D) were more ubiquitous on ungrazed units, but *C. arvense* decreased with increasing numbers of grazes (Table 2.2). Biennial *T. dubius* increased with increasing grazing (Table 2.2). Twenty-four of thirty-six observations (one reversed) differed from those at Lostwood NWR.

The performance (cover) of four of nine weeds was influenced by grazing. *Bromus inermis* (C) and *C. arvense* (B) increased with years since grazing, as if they compete well in ungrazed native vegetation (Table 2.2). Reciprocally, *Poa pratensis* (A) decreased with years since grazing (Table 2.2). At Lostwood NWR, *B. inermis* is less (D) and *Poa pratensis* is more productive on grazed than ungrazed sites (Table 2), perhaps due to palatability, grazing, or past management. *Symphoricarpos occidentalis* and *T. dubius* both increased with increasing numbers of grazing treatments (Table 2), perhaps because grazers eliminate/weaken their competitors.] Seven of the thirty-six observations differed from those at Lostwood NWR.

Unexplained variance. Forces expected to explain much of weed distribution - - environmental type, fire history, and grazing history - - actually explain little of it. While all have highly significant effects, in total, they explain only 2-15%, depending on the weed considered, of the variance in ubiquity (Table 2.2) and only 0-40% of their dominance (% cover) at sites they occupy (Table 2.2). The following paragraphs repeat the discussion of other contributing factors from the Lostwood section (Chapter 1) of this report.

The remaining variance must be due to either to factors affecting dispersion or establishment. 1) Weeds obviously decline from county roads through pasture roads to untracked rangeland. While all our samples were greater than 10 meters from and less than 400 meters from a road, we have not accounted for variance, within that band, due to distance from a road. Future investigation of weed distribution should include measurement of weed frequency and cover as a function of distance from roads of different magnitudes. 2) While some weeds obviously spread from established patches (e.g., from an old field seeded to brome), we have not accounted for distribution from the nearest stand. Future investigation could include an estimation of proximity to seed sources, measuring the distance and direction of the nearest seed source areas, and correlating infestation with source proximity. 3) Some dispersal may be truly random. This might be especially so for wind dispersed seeds like *P. tremuloides*, *T. dubius*, and *C. arvense*. It might be least so for seeds transported by animals to specific environments—such as those borne in berries (e.g., *S. occidentalis*, *E. commutata*, and *E. esula*) or with digestion resistant seed coats (e.g., *M. officinalis*). While *B. inermis* is neither winged nor animal borne, the fact that it forms a density gradient adjacent to old brome fields suggest that it is wind or small mammal dispersed.

Seedbed quality will also affect establishment/presence. 1) Besides their influence on dispersal, road shoulders provide 'cultivated' sites with reduced competition. Our stratification with respect to distance from roads surely reduced this effect even more effectively than it reduced the dispersal-from-roads effect. 2) A factor that varied among units (=pastures) without correlation either to fire or grazing could account for unexplained weed distribution. We mention three possibilities. Soils vary (become sandier) from north to south across the moraine/refuge (VanderBusch 1991, Rolling and Dhuyvetter 2003). Past

management probably/undoubtedly varies since some units were nearer homesteads than others and thus one can imagine residual effects of grazing and fire management. Small mammals, as burrowers/planters, might vary with soils (or management histories). [While variance in soils and pre-1930 management may be among the most likely sources of unaccounted for variance, we did not test for them in the analysis of our management experiment because subdividing the sample further would have reduced sample sizes excessively. These effects might be investigated by adding measurements of soil quality and management history to regressions of weed presence vs. likely factors.]

Management of major species. While one can deduce effects of management for any of our species from Tables 2.2 and 2.3, we explicitly outline the management implications of fire and grazing treatment for three especially offensive plants.

Recall first, that, while the effects of fire and grazing are often very significant, they explain little of the variance in weed distribution. Thus, the comments below should be applied, not in planning the management of these weeds, but in projecting what will be the effect on these weeds of fire/grazing treatments/management applied for other reasons. We have no evidence that any of the weeds in this study can be controlled by fire or grazing alone or in concert. This is contrary to observations from the tall grass prairie, where fire and grazing can be used to control cool season weeds (Willson 1992, Grilz and Romo 1994, Willson and Stubbendieck 1996).

Bromus inermis was little affected by fire and grazing. The ubiquity (frequency) of brome increased slightly with number of burns (Table 2.2). Effects of fire on *B. inermis* ubiquity were greater on ungrazed than grazed units (Table 2.4), as if the higher fuel load/fire temperature were more damaging. The interaction of fire and habitat on brome cover describes the fact that brome cover declined slightly on burned hilltops. Consider grazing. *Bromus inermis* ubiquity increased slightly with number of grazes (B), as if grazing favored it, but was unaffected at Lostwood NWR. But it also decreases (C) inconsistently with time since grazing, as if grazing maintains it. Its cover also increases with years since grazing (C), again as if it is recovering from grazing inhibition. [*Bromus inermis* responses at Des Lacs NWR are often inconsistent with those observed at Lostwood NWR. At Lostwood NWR *B. inermis* ubiquity was decreased by fire alone. But while its

ubiquity declined upslope with fire (burn x graze, Table 2.4), its cover was not affected by the fire x habitat interaction (Table 2.2). Its ubiquity was not increased by grazing.]

While *P. pratensis* was slightly affected by burning it was apparently not affected by grazing. *Poa pratensis* ubiquity increased with number of burns (C) and without regard to habitat, and so was more common (C) on burned than unburned sites. Despite the negative interaction term, its cover is unaffected reduced by burning in any habitat but the cumulative effect appeared to be positive. While it was not bolstered by grazing, its cover decreased with years since grazing (A), as if it were excluded by recovering natives. *Poa pratensis*'s responses at Lostwood and Des Lacs NWR were inconsistent. While not responding to other fire factors, its ubiquity at Lostwood NWR declined with years since burn (B) and its cover increased (D) with years since burn. Both ubiquity (B) and cover (C) increased with cumulative grazing.

Symphoricarpos occidentalis was little influenced by burning or grazing. It was more ubiquitous (A) and had more cover (D) on burned than unburned sites. Fire reduced both ubiquity (C) and cover (C) on grazed sites. Its ubiquity fell with both years since burning and years since grazing, as if both disturbances supported its presence. [*Symphoricarpos occidentalis*' responses were inconsistent between the sites, but its cover was unaffected by this factor. Lostwood ubiquity was unaffected by either fire nor grazing. Its cover, at Lostwood, was increased by fire, not burn x habitat influenced and more reduced later in the season, and it increased with number of grazes, as if grazing inhibited its competitors.]

Comparison of Lostwood and Des Lacs conclusions. Chapter 1 described weed behaviour at Lostwood NWR. Observations at Lostwood and Des Lacs NWR often differ and these were regularly mentioned. We concentrate our discussion of these differences in chapter 3, we note here that the differences might either be random or due to environmental differences between nearby refuges.

First, we suggest that the observed differences in weed performance are random, that is, when the responses are very small, slopes (regression lines) might be 'tipped' by random points. Alternatively, conditions at the refuges might somehow induce 'opposite' effects.

While we doubt this and will not pursue them, we list candidate differences. Lostwood NWR is located on an immense moraine and Des Lacs NWR is on the till plain; thus the relief at Des Lacs NWR is lower and soils are less rocky ('richer'). While both refuges were created in 1935, prescribed burning at Lostwood NWR was instituted first (1975-1979 vs 1987), so Des Lacs NWR treatments are of shorter duration. While Lostwood NWR is isodiametric, Des Lacs NWR is distributed linearly along the Des Lacs river; thus Des Lacs NWR has a greater perimeter for invasion and more fence-line for exotic reservoir. Ducks have received greater emphasis in the management of Des Lacs than Lostwood NWR; management for litter was probably beneficial to *Bromus inermis*, *Poa pratensis*, *Cirsium arvense*, and native *Urtica diotica*.

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Table 2.1. **Fire (# burns) and grazing (ungrazed vs. lightly grazed) history** (1972-2002) of 3 management units (in 2002) and 20 management units (in 2003) at **Des Lacs National Wildlife Refuge**, Kenmare ND. Data collected were used to determine invasiveness (frequency) and success (= dominance (cover)) of nine weeds in four environments (bottoms, s-slopes, n-slopes, hilltops), fire treatment (burn vs. no burn, # burns, time since burn, season of burn) grazing treatment (graze vs. no graze, # grazes and time since grazing), and interaction between grazing and number of burns (See Table 2.2).

# Burns	0	1	2	3	4	5	6	7
2002 sampled								
Ungrazed								
Grazed	2		1					
2003 sampled								
Ungrazed				1	2	1	1	
Grazed	1	4	2	4	1	2		1
Total sampled								
Ungrazed				1	2	1	1	
Grazed	3	4	3	4	1	2		1

Table 2.2. **Invasiveness (frequency) and success (= dominance (cover)) of nine weeds** in four environments (bottoms, s-slopes, n-slopes, hilltops), fire treatment (burn vs. no burn, # burns, time since burn, season of burn) grazing treatment (graze vs. no graze, # grazes and time since grazing), and interaction between grazing and number of burns on **Des Lacs National Wildlife Refuge**. Responses are indexed with coefficients of a multiple regression of each species against the seven environmental variables. The significance of each response is indicated by a probability class: A≤0.001, B≤0.01, C≤0.05, D≤0.10, E≤0.15, n (or --) = not significant.

Factor[1]	Adjr[2]	C	Ht	Burn[3]	#Brn	B x Ht[3]	Seasn B	Yr.S.B	Gr[3]	# Gr	Yr.S.G	GxB[3]
Invasiveness (frequency)												
Brin[2]	0.15	0.1n	0.06C	--	0.07A	--	--	--	--	0.03B	0.02C	0.05A
Popr	0.08	0.36B	0.13B	-0.08C	0.07C	-0.02D	--	--	--	--	--	0.03E
Syoc	0.15	0.6A	--	-0.17A	--	--	--	-0.02A	--	--	-0.02B	0.02D
Potr	0.02	-0.08D	--	--	--	0.01B	--	--	--	--	--	-0.02D
Elco	0.02	1.2A	--	--	--	--	--	--	--	--	-0.09C	--
Eues	0.06	0.10A	--	--	-0.02B	--	--	-0.00D	-0.03C	--	-0.01C	--
Ciar	0.13	0.25B	-0.06C	--	-0.04D	0.01E	**--**	--	-0.08D	-0.01E	0.01B	0.02D
Meof	0.06	0.02n	0.02C	--	--	-0.00C	**--**	--	**--**	--	-0.00E	0.01B
Trdu	0.10	0.13A	--	0.11A	--	--	--	0.01A	--	0.01B	--	--
Dominance (cover)												
Brin[2]	0.06	16.02A	--	--	--	-0.77A	--	--	--	--	1.20C	--
Popr	0.14	4.26n	9.65A	-6.47C	-3.58E	--	--	0.65D	--	--	-1.8A	--
Syoc	0.04	14.97A	--	-3.27D	--	-1.52E	0.47C	--	--	0.76D	--	-0.64D
Potr	--	--	--	--	--	--	--	--	--	--	--	--
Elco	0.00	9.47B	--	--	0.53n	--	--	--	--	--	--	--
Eues	0.40	3.14A	--	1.79A	--	--	--	--	--	--	--	--
Ciar	0.15	0.87C	--	--	--	--	--	--	--	--	0.17B	--
Meof	--	--	--	--	--	--	--	--	--	--	--	--
Trdu	0.00	2.62B	--	--	-0.25n	--	--	--	--	--	--	--

[1] Factors tested (column headings) are adjusted r^2 (Adjr[2]), intercept (C), habitat (Ht; denoted by drier sites having a higher code number), Burn (+ (burned) or – (unburned)), number of burns (#Brn), # burns by habitat interaction (B x Ht), season of burn (denoted by later seasons having a higher code number), years since burning (Yr.S.B), grazing (Gr; + (grazed) or – (ungrazed)), # grazing events (# Gr), years since grazing (Yr.S.G.), and graze by # burn interaction (GxB).

[2] Weed species include grasses (*Bromus inermis* and *Poa pratensis*), shrubs/trees (*Symphoricarpos occidentalis*, *Populus tremuloides,* and *Elaeagnus commutata*), perennial forbs (*Euphorbia esula* and *Cirsium arvense*) and biennial forbs (*Melilotus officinalis* and *Tragopogon dubius*).

[3] Interpretation of four columns is less than straightforward. The sign of the cumulative burns and grazing is counterintuitive; a positive coefficient indicates a decline and vice versa. The sign of the interaction terms (e.g., burn x ht and grazing x fire) is meaningless; a significant interaction is examined by testing the components separately, e.g., effect of fire in each habitat and effect of grazing on burned and unburned sites.

Table 2.3. **Comparison of burn (# burns) effect between four environments** (bottom, n-slope, s-slope, and top) on **Des Lacs National Wildlife Refuge**[1]. Invasion (frequency) and establishment (cover) capacity of nine species are recorded. The burn coefficient found in multiple regressions run for each weed species and environment is shown. The significance of each response is indicated by a probability class: A≤0.001, B≤0.01, C≤0.05, D≤0.10, E≤0.15, n = not significant.

Environment	Bottom	North Slope	South Slope	Hilltop
	Fire x invasability (frequency)			
BRIN	-0.01n	-0.017n	-0.010n	-0.056B
POPR	0.009n	0.002n	0.016n	-0.018n
SYOC	0.001n	-0.005n	-0.005n	-0.036D
POTR	-0.002n	-0.004n	-0.015C	-0.029A
CIAR	-0.050A	-0.019C	-0.010n	-0.018C
MEOF	0.005n	0.002n	-0.020B	-0.009n
	Fire x success (cover)			
BRIN	0.15n	-1.89C	-1.02n	-1.57D
POPR	0.62n	0.07n	0.53n	-0.77n
SYOC	0.71n	-0.46n	-0.86D	-0.42n

Weeds are *Bromus inermis* (BRIN), *Poa pratensis* (POPR), *Symphoricarpos occidentalis* (SYOC), *Populus tremuloides* (POTR), *Cirsium arvense* (CIAR), and *Melilotus officinalis* (MEOF).

[1]The Ht x burn interaction was seen only at DLR, not at LWR.

Table 2.4. **Comparison of burn (# burns) effect for grazed and ungrazed sites** on **Des Lacs National Wildlife Refuge**[1]. Invasion (frequency) and establishment (cover) capacity of species that had a significant burn x graze interaction are recorded (See Table 2.2). The burn coefficient found in multiple regressions run for each weed species in grazed and ungrazed environments is shown. The significance of each response is indicated by a probability class: $A \leq 0.001$, $B \leq 0.01$, $C \leq 0.05$, $D \leq 0.10$, $E \leq 0.15$, n (or --) = not significant.

Grazing Treatment	Grazed	Ungrazed
Fire x invasability (frequency)		
BRIN[1]	-0.004n	-0.085A
POPR	-0.009n	0.020n
SYOC	-0.026C	0.020n
POTR	-0.005D	-0.030A
CIAR	-0.019A	-0.035A
MEOF	-0.011A	0.012E
Fire x success (cover)		
BRIN	--	--
POPR	--	--
SYOC	-0.705C	0.761E

[1]Weeds are *Bromus inermis* (BRIN), *Poa pratensis* (POPR), *Symphoricarpos occidentalis* (SYOC), *Populus tremuloides* (POTR), *Cirsium arvense* (CIAR), and *Melilotus officinalis* (MEOF).

Table 2.5. **Number and percent of plots with each of the nine weed species present (i.e., cover > 0)**.
Data are presented as the percent across all sites and also the percent within each habitat
(bottom, North-slope, South-slope, and hilltop) on **Des Lacs National Wildlife Refuge** (n=276 sites).

	ENVIRONMENT				
	All habitats	Bottom	North slope	South slope	Hilltop
	N=276	N=35	N=73	N=42	N=126
BRIN[1]	72	71	74	69	73
POPR	93	86	92	90	97
SYOC	84	80	93	83	80
POTR	1	0	0	0	2
ELCO	25	20	38	29	18
EUES	11	11	15	17	6
CIAR	17	37	19	14	10
MEOF	10	6	11	12	10
TRDU	16	6	12	26	17

[1]Weeds are *Bromus inermis* (BRIN), *Poa pratensis* (POPR), *Symphoricarpos occidentalis* (SYOC), *Populus tremuloides* (POTR), *Elaeagnus commutata* (ELCO), *Euphorbia esula* (EUES), *Cirsium arvense* (CIAR), *Melilotus officinalis* (MEOF), and *Tragopogon dubius* (TRDU).
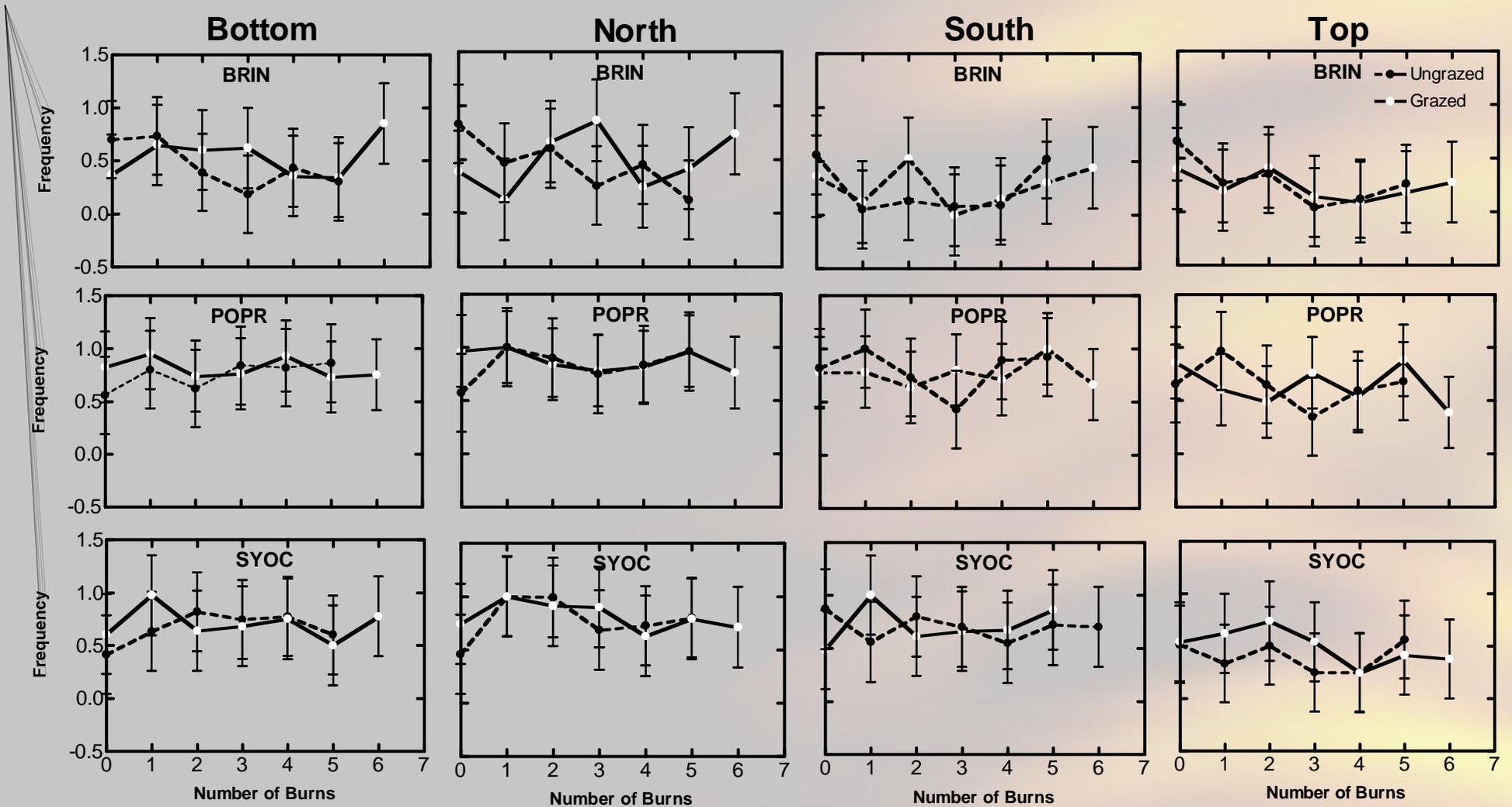
Figure 2.1. Ubiquity (frequency) of three invasive species of mixed grass prairie (*Bromus inermis* (BRIN), *Poa pratensis* (POPR), *Symphoricarpos occidentalis* (SYOC)) as influenced by habitat (bottom, North slope, South slope, hilltop), number of burns, and grazing (grazed (open symbol) vs. ungrazed (closed symbol).
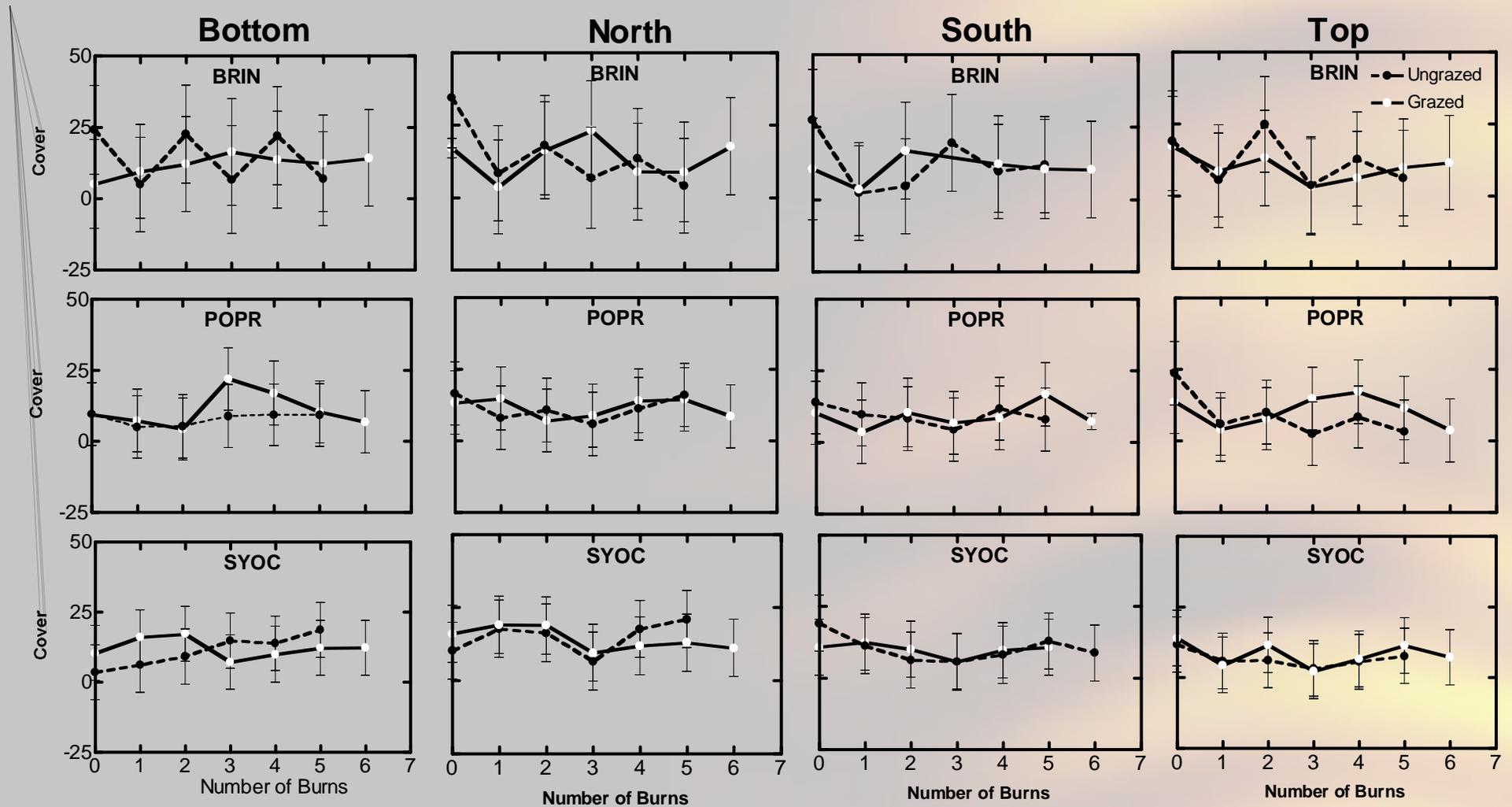
Figure 2.2. Success (% cover) of three invasive species of mixed grass prairie (*Bromus inermis* (BRIN), *Poa pratensis* (POPR), *Symphoricarpos occidentalis* (SYOC)) as influenced by habitat (bottom, North slope, South slope, hilltop), number of burns, and grazing (grazed (open symbol) vs. ungrazed (closed symbol).

CHAPTER 3

Effect of fire and grazing
on invasive species of northern mixed grass prairie:
cross site comparisons and conclusions

We recognize fire and grazing as basic and important to prairie processes. Three examples follow. Whether or not fire affects shrub/tree ubiquity/cover, it regulates aboveground biomass. An important example is, while the cover of *Symporicarpos occidentalis* may have been constant since presettlement times, post settlement fire suppression may have made it more conspicuous/influential and reinstitution of fire is expected to reduce its influence. Both fire and grazing reduce litter, and in the process influence community composition/process through affects on phenomena such as soil water, soil temperature, microbial populations, nutrient cycling, ground layer light and humidity. Both affect wildlife habitat via structural modifications ranging from ground cover to tree perches.

The objective of this project is to evaluate fire and grazing as tools for management of weeds. We have therefore studied the behavior of nine weeds in a remarkably robust management experiment (6 fire treatments x 2 grazing treatments x 4 habitats x ~776 reps x 35 years). Ubiquity (colonization frequency) and dominance (clonal cover extension) responses were observed. To reiterate, it is our objective to recognize the correlation (causation) of weed response with potential weed management tools (fire and grazing) and not to determine what actually causes the distribution and success of any weed. Our objective was **not** to determine what actually causes the distribution and success of any weed. While irrelevant to our paper, other possible causes of the variation observed are pattern in dispersal, pattern in establishment, and unrecognized pattern in the environment of the refuges. These are discussed in chapters 1 and 2. The weeds studied include three

woody plants (*Symphoricarpos occidentalis* Hook., *Elaeagnus commutata* Bernh., *Populus tremuloides* Michx.), two perennial grasses (*Bromus inermis* Leyss. and *Poa pratensis* L.), two perennial forbs (*Euphorbia esula* L. and *Cirsium arvense* L.) and two biennial forbs (*Melilotus officinalis* L. and *Tragopogon dubius* L.).

Burning and grazing account for little of the variation in weed ubiquity or dominance at either Lostwood or Des Lacs NWRs. R^2 for ubiquity were 1-9% at Lostwood and 2-15% at Des Lacs NWR. R^2 for dominance were 0-10% at Lostwood (Table 2.2, Chapter 1) and 0-40% at Des Lacs (Table 2.2, Chapter 2).

In multiple regressions of ubiquity or dominance against presumptive factors, significance levels were greater (or much greater) than 5%,that is, weeds are certainly affected by fire/grazing management. Consider **ubiquity** (frequency). Habitat (water) was influential for 8/9 weeds at Lostwood and 4/9 weeds at Des Lacs NWR. Some facet of fire was influential at 5/9 weeds at Lostwood and 6/9 weeds at Des Lacs NWR. Some facet of grazing was influential at 5/9 weeds at Lostwood and 6/9 weeds at Des Lacs NWR. Consider **dominance** (cover). Habitat (wetness) was never influential at Lostwood and was only influential for *Poa pratensis* at Des Lacs NWR. Some facet of fire was influential at Lostwood in 6/9 weeds and 4/9 weeds at Des Lacs NWR. Some facet of grazing was influential in 3/9 weeds at Lostwood and 3/9 weeds at Des Lacs NWR.

While often significant (<5%), coefficients (slopes) of the regression lines show that fire and grazing have no strong effects on our weeds (Table 2 in Chapters 1 and 2). Consider **ubiquity** (frequency). They ranged from 0-0.02-0.07 at Lostwood and 0-0.02-0.13 at Des Lacs NWR. For fire they ranged from 0.01-0.05 at Lostwood and 0-0.01-0.17 at Des Lacs NWR. For grazing they ranged from 0-0.01-10 at Lostwood and 0-0.01-0.08 at Des Lacs NWR. The relationships between **dominance** (cover) and specific factors were also weak. The ranged from 0-0.4-10 at Lostwood (all insignificant) and were all zero at Des Lacs NWR, except for *Poa pratensis* (9.65A). For fire they ranged from 0-0.35-11.5 at Lostwood and from 0-0.5-.47 at Des Lacs NWR.

If a relationship is to be of general management use, it must be consistent between sites. Consistency is expressed as the percentage of cases (out of 9 for habitat, 45 for fire, and 36 for grazing Table 3.1) in which a significant coefficient for one weed and site (Lostwood) agrees in sign with the coefficient for the same weed at the second site (Des Lacs). True consistency (i.e., cases in which regression slopes at Lostwood and Des Lacs agree) is 2-7% (i.e., inconsistency 93-98%, Table 3.2). Inconsistency (opposite slopes or where no slope is paired with a slope) is 11-66%). For the fire treatments Lostwood and Des Lacs results are often inconsistent for ubiquity (35%) and cover (25%, Table 3.2). Under grazing treatment the responses are inconsistent for ubiquity (42%) and cover (17%). For the habitat treatments results are inconsistent for ubiquity (66%) and cover (11%). If one relaxes the significance level required for recognition of a slope from $p<5\%$ to $p<15\%$ the inconsistency rates rise (Table 3.2). What consistency there is comes from the considerable excess (noted previously) of cases in which there is no significant relationship between fire, grazing, or habitat factors and weed behaviour (i.e., no real consistency, Table 3.2).

We conclude that, while facets of fire and grazing are highly correlated ($p=0.0001$-0.05), weed ubiquity and dominance have little influence on weed presence. That is, a treatment has little impact on our weeds, i.e., the slope of the regression describing the relationship of weed response to treatment. Our conclusion is reinforced by weed-by-weed comparison of responses at Lostwood and Des Lacs NWRs. Since the sites are similar, we expect parallel slopes. Instead, lines seem to tip slightly (+, 0, -) and independently. One might speculate that fire/grazing effects are zero and that regression lines rotate randomly around zero on the basis of a few odd points.

Our conclusion for the manager is that, while fire is a useful tool in prairie management (e.g., for litter and woody overstory), it has little value for controlling the colonization or vegetative spread, in mixed grass prairie, of shrubs/trees, perennial grasses, perennial forbs, or biennial forbs. This result is contrary to observations made in the tall grass prairie, because- - while the treatment can be phenologically targeted there- - the fact that both weeds and dominant grasses are cool-season plants prevents phenological targeting in the mixed grass prairie. Future research effort should be used to develop new selective control forces, rather than to pursue further low yield studies of fire and grazing tools.

Table 3.1. **Comparison of three primary invasive species on Lostwood and Des Lacs NWRs**, showing invasiveness (frequency) and success= dominance (cover) of nine weeds in four environments (bottoms, n-slopes, s-slopes, hilltops), fire treatment (# burns, time since burn, season of burn) and grazing treatment (# grazes and time since grazing). Responses are indexed with coefficients of a multiple regression of each species against the seven environmental variables. The significance of each response is indicated by a probability class, A< 0.001, B<0.01, C<0.05, D<0.10, E< 0.15, n = not significant. Normal font indicates results obtained on Lostwood NWR; bold font indicates results obtained on Des Lacs NWR.

Factor[1]	Adjr[2]	C	Ht	Burn	#Brn	B x Ht	Seasn B	Yr.S.B	Gr	# Gr	Yr.S.G	GxB
					Invasiveness (frequency)							
Brin²	**0.15**	**0.1n**	**0.06C**	--	**0.07A**	--	--	--	--	**0.03B**	**-0.02**	**0.05A**
Brin²	0.06	0.5A	-0.05C	--	--	-0.01B	--	0.01E	--	--	--	--
Popr	**0.08**	**0.36B**	**0.13B**	**-0.08C**	**0.07C**	**-0.02D**	--	--	--	--	--	**0.03E**
Popr	0.06	1.0A	-0.06A	--	--	--	--	-0.02A	-0.10B	-0.02D	--	--
Syoc	**0.15**	**0.6A**	--	**-0.17A**	--	--	--	**-0.02A**	--	--	**-0.02B**	**0.02D**
Syoc	0.06	0.9A	-0.07A	--	--	-0.01D	--	--	--	--	--	--
Potr	**0.02**	**-0.08D**	--	--	--	**0.01B**	--	--	--	--	--	**-0.02D**
Potr	0.05	-0.0n	0.04A	--	0.01E	-0.01B	--	--	0.01D	--	--	--
Elco	**0.02**	**1.2A**	--	--	--	--	--	--	--	--	**-0.09C**	--
Elco	0.01	0.2A	--	--	--	--	--	--	0.09B	0.03B	--	--
Eues	**0.06**	**0.10A**	--	--	**-0.02B**	--	--	**-0.00D**	**-0.03C**	--	**-0.01C**	--
Eues	0.03	0.0n	0.02B	--	--	-0.01B	--	--	0.04A	0.01B	--	--
Ciar	**0.13**	**0.25B**	**-0.06C**	--	**-0.04D**	**0.01E**	--	--	**-0.08D**	**-0.01E**	**0.01B**	**0.02D**
Ciar	0.09	0.3A	-0.06A	--	-0.05A	0.01C	--	-0.01A	--	--	--	--
Meof	**0.06**	**0.02n**	**0.02C**	--	--	**-0.00C**	--	--	--	--	**-0.00E**	**0.01B**
Meof	0.03	-0.0n	0.02B	--	--	-0.01B	--	--	0.04A	0.01B	--	--
Trdu	**0.10**	**0.13A**	--	**0.11A**	--	--	--	**0.01A**	--	**0.01B**	--	--
Trdu	0.05	0.0C	0.02A	--	-0.01A	--	--	--	--	0.01B	--	--

Table 3.1 (continued)

Factor[1]	Adjr[2]	C	Ht	Burn	#Brn	B x Ht	Seasn B	Yr.S.B	Gr	# Gr	Yr.S.G	GxB
					Dominance (cover)							
Brin[2]	**0.06**	**16.02A**	--	--	--	**-0.77A**	--	--	--	--	**1.20C**	--
Brin[2]	0.02	14.8A	--	--	--	-0.35C	--	--	1.71D	--		
Popr	**0.14**	**4.26n**	**9.65A**	**-6.47C**	**-3.58E**	--	--	**0.65D**	--	--	**-1.8A**	--
Popr	0.05	11.2A	--	--	--	--	-5.54A	5.28A	-1.11C	--		
Syoc	**0.04**	**14.97A**	--	**-3.27D**	--	**-1.52E**	**0.47C**	--	--	**0.76D**	--	**-0.64D**
Syoc	0.05	11.6A	--	--	0.84C	-0.47A	-0.29C	--	--	0.54C	--	--
Potr	--	--	--	--	--	--	--	--	--	--	--	--
Potr	0.00	-4.2n	3.04n	--	1.81n	-0.99n	-6.35n	7.91n	4.80n	1.18n	--	--
Elco	**0.00**	**9.47B**	--	--	**0.53n**	--	--	--	--	--	--	--
Elco	0.05	3.7A	-0.44E	--	0.55A	--	-1.3E	1.15E	--	--	--	--
Eues	**0.40**	**3.14A**	--	**1.79A**	--	--	--	--	--	--	--	--
Eues	0.00	-28.2n	10.49n	--	11.47n	-2.52n	-7.24n	8.96n	-13.18n	--	--	--
Ciar	**0.15**	**0.87C**	--	--	--	--	--	--	--	--	**0.17B**	--
Ciar	0.00	1.01n	0.37n	--	0.21n	-0.14E	0.49n	-0.52n	0.25n	--	--	--
Meof	--	--	--	--	--	--	--	--	--	--	--	--
Meof	0.10	-3.01n	1.44D	--	1.98B	-0.67C	--	--	--	--	--	--
Trdu	**0.00**	**2.62B**	--	--	**-0.25n**	--	--	--	--	--	--	--
Trdu	0.05	0.42A	--	--	0.04C	--	--	--	--	0.03C	--	--

[1] Factors tested (column headings) are adjusted r^2 (Adjr^2) intercept, habitat=environment with drier sites having a higher code number, # burns, habitat x # burns interaction, season of burn with later seasons having a higher code number, years since burning, grazing (+or -), and # grazing events.

[2] Weed species include grasses (*Bromus inermis* and *Poa pratensis*), shrubs/trees (*Symphoricarpos occidentalis, Populus tremuloides,* and *Elaeagnus commutata*), perennial forbs (*Euphorbia esula* and *Cirsium arvense*) and biennial forbs (*Melilotus officinalis* and *Tragopogon dubius*).

[3] Interpretation of four columns is less than straightforward. The sign of the cumulative burns and grazing is counterintuitive; a positive coefficient indicates a decline and vice versa. The sign of the interaction terms (e.g., burn x ht and grazing x fire) is meaningless; a significant interaction is examined by testing the components separately, e.g., effect of fire in each habitat and effect of grazing on burned and unburned sites.

Table 3.2. Agreement between Lostwood and Des Lacs NWR treatments with respect to the sign of regression slopes. A model for evaluating these results is presented below.

Response	Consistent neither sloped	both same	Not consistent one sloped	both, opposite	Number of cases
		Fire effects			
Ubiquity p<05	63	2	33	2	45
Ubiquity p<15	51	7	40	2	45
Cover p<05	71	1	24	1	45
Cover p<15	62	7	29	2	45
		Grazing effects			
Ubiquity p<05	56	3	39	3	36
Ubiquity p<15	31	3	64	3	36
Cover p<05	83	0	17	0	36
Cover p<15	78	3	19	0	36
		Habitat effects.			
Ubiquity p<05	11	22	44	22	9
Ubiquity p<15	11	22	44	22	9
Cover p<05	89	0	11	0	9
Cover p<15	66	0	33	0	9
Predicted %	11	44	22	22	

1) Slopes may be positive (rising to the right), neutral, or negative.
2) One might assume that the probability of positive, neutral, and negative slopes were equal.
3) If so, the probability of two neutral slopes at 11%, one neutral/one +or - slope at 44%, two slopes with the same sign at 22%, and two opposite at 22%. The calculation was made by use of a Punnett square with (-0+) on each axis.
4) We tabulated the number of cases of each type separately for ubiquity and cover. The calculations were made twice. Once where the random likelihood (significance) of the slope was less than 5% and once where it was less than 15%. These are presented above.
5) The probability of consistency (same slopes) is very low (2-7%), the probability of inconsistency (opposite slopes on only one sloped) is high (11-67%) and the probability of similarity due to no environmental effect is extremely high (11-89%)

Appendix 1.

ABSTRACTS

from a project sponsored workshop:

Invasive species management in Northern Great Plains prairies

Presented in conjunction with the
North Dakota Department of Agriculture, U.S. Fish and Wildlife Service, ND Game and Fish Department, ND Parks and Recreation Department, ND Chapter of The Wildlife Society, ND Weed Control Association, USDA Natural Resources Conservation Service, and U.S. Forest Service
Invasive Species Workshop, April 2005

ABSTRACT. Research on weeds of the mixed grass prairie was reviewed [with respect to invasion, impact, control, and restoration]. Brief abstracts[2] from our workshop outline the discussion and author contact information to provide access to more information.

Evaluation of ecosystem effects of type conversation by weed invasion may involve species richness, productivity, phenology and environment (Weaver).

Undisturbed grassland is invasion resistant (Weaver), but weakening can be recognized (Printz) and remedied.

Weed management may involve chemicals (Beran), integrated control (prevention, herbicide, grazing, and biocontrol; Prosser) or fire and grazing (Smith).

Results of management might be measured on-the-ground (Hartz –Rubin) or from a satellite (Hurst).

Restoration of exotic dominated sites was reviewed (Smith).

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[1]The workshop was presented as a workshop in the Invasive Species Workshop,[3] Bismarck, ND, April 5-7, 2005. It was organized by J Hartz-Rubin (Biology Department, Rochester Community and Technical College, Rochester, MN 55904) and T Weaver (Ecology Department, Montana State University, Bozeman, MT 59717).

[2]Abstracts for all papers in the entire workshop are found at
http://www.agdepartment.com/noxiousweeds/Abstract_Proceedings.pdf

[3]More information about the Invasive Species Workshop[4] can be found at
http://www.agdepartment.com/noxiousweeds/Symposium.asp

[4] A web-based manual with many links and specific information on invasive species can be found at
http://www.agdepartment.com/noxiousweeds/index.asp

SHORT ABSTRACTS OF WEED SYMPOSIUM PAPERS.

a. EFFECTS OF WEED INVASION IN MIXED GRASS PRAIRIE[1].   T Weaver & J Plaggemeyer. *Montana State University, Bozeman, MT,* tWeaver@montana.edu

Invaders of management concern include clonal *Bromus inermis* and *Symphoricarpos occidentalis*. To study the effects of invasion we measured ecosystem qualities in healthy prairie and in clones of brome and snowberry imbedded in it. Parameters measured included community qualities (eg species dominance, species richness, productivity, phenology) and environmental qualities (eg soil water and temperature). Differences observed provide some bases for comparing the value of the systems and managing them.

b. INVADABILITY OF HEALTHY SOD IN MIXED GRASS, SHORTGRASS AND BUNCHGRASS STEPPE. *T Weaver, L Payson, and J Plaggemeyer. Montana State University, Bozeman, MT, tWeaver@montana.edu.*

Seeds of weeds (eg *Centauria*) and simulated weeds (eg barley and sunflower) were planted into healthy grasslands in North Dakota and Montana. Performance was poor, regardless of species considered, habitat richness, or habitat fire history. Underlying mechanisms are considered.

c. INDICATORS OF INCIPIENT INVADABILITY AND MANAGEMENT TO PREVENT/REMEDY IT. *J Printz, State Rangeland Management Specialist, USDA Natural Resources Conservation Service, Bismarck, ND, jeff.printz@nd.usda.gov*

Native prairie is more invadable when overtaxed than healthy. I consider ways of recognizing overtaxed vegetation and management to prevent or reduce degradation.

d. USE OF HERBICIDES IN MANAGEMENT OF WEED INVASION IN (DRIER) MIXED GRASS PRAIRIE. *D Beran, Market Development Specialist, BASF Corporation, Des Moines, IA, berand@basf.com*

Herbicides are one of the most used tools for managing exotics and other unwanted plants in native range. This talk/discussion considers 1) control of introduced grasses (eg *Bromus inermis* and *Poa pratensis*), 2) preserving the forb/shrub component, 3) control of invasive broadleaf weeds, and 4) integration of herbicides with other restoration methods.

e. WEED MANAGEMENT IN NATIONAL PARKS OF THE SHORTGRASS PRAIRIE. *C Prosser, Theodore Roosevelt National Park, Medora, ND, chad_prosser@nps.gov*

Law and policy demand weed control. Expansion of natives (eg *Symphoricarpos*) conflicting with other values suggest imbalances in fire or grazing management that can be corrected. Unwanted exotics might be contained by preserving range condition, spot treating with herbicide, integrating herbicide with biocontrol insects and/or fire. Experience in these areas is reviewed.

f. EFFECTS OF FIRE AND GRAZING ON LOSTWOOD VEGETATION, 1974-2004. *K Smith, Lostwood National Wildlife Refuge, Kenmare, ND, prairie@restel.net*

Fire treatment was first applied to control excessive dominance of aspen and snowberry detrimental to birds and mammals native to mixed grass prairie. In recent years we have tested fire and grazing as tools for control of exotic grasses (*Bromus inermis* and *Poa pratensis*), as well. Theory is outlined and results - - both on plants and animals - - are reviewed.

g. IKONOS VIEW OF FIRE /GRAZING EFFECTS AT LOSTWOOD. *R Hurst, Montana State University, Bozeman, MT, tWeaver@ Montana.edu*

When managing rangeland managers must compare periodic snapshots of condition to determine whether treatments should be continued or modified. Successive snapshots with sufficient detail might be available in high resolution satellite images. We test this possibility by examining differences in space (rather than time) across fence lines separating different long-term grazing management treatments. We can distinguish dry dwarf shrub/ grass, grass, shrub (mostly *Symphoricarpos*), aspen, and lake vegetation. You will see our first qualitative tests. Statistical analysis will follow.

h. GROUND BASED MEASUREMENT OF FIRE/ GRAZING EFFECTS AT LOSTWOOD AND DES LACS NWR, WESTERN NORTH DAKOTA. [1]
J Hartz-Rubin, Rochester Community and Technical College, Rochester, MN, Jennifer.Rubin@roch.edu

We seek to detect effects of long-term fire/grazing management on species of management concern. 500 (Lostwood) and 300 (DesLacs) random points stratified among hilltop (xeric), south-facing, north-facing and bottom (mesic) sites were sampled with multiple quadrats for presence and dominance. While differences among communities with 0-7 burns and no vs repeated grazing may exist, few are statistically significant. Additional sampling, more sophisticated analysis, or well controlled experiments may teach us more. Input is sought.

i. RESTORATION OF EXOTIC DOMINATED MIXED GRASS PRAIRIE SITES.
K Smith, Lostwood National Wildlife Refuge, Kenmare, ND, prairie@restel.net

Many sites with mixed grass prairie potential are/can be dominated by *Bromus inermis* or *Poa pratensis*. Reclamation of sites 'beyond help' is one management option. In the ideal, one might restore these sites by removing all vegetation and replanting it with mixed grass prairie species. Strategy and success of this approach at Lostwood National Wildlife Refuge are described.

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[1] Longer, more informative, abstract provided below.

EXTENDED ABSTRACTS OF THREE PAPERS.

ECOSYSTEM EFFECTS OF CLONAL WEED INVASION OF MIXED GRASS PRAIRIE

T. Weaver and J. Plaggemeyer, Ecology Department, Montana State University, Bozeman MT 59717
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While most environments can support alternate communities, managers rarely know the full effects of a type conversion and their knowledge rarely comes from equilibrium systems. To demonstrate the many facets of type conversion, we compare three systems all important in the mixed grass prairie environment of the central great plains: the native grass (*Stipa comata/Agropyron smithi/Schizachyrium scoparium Bouteloua gracilis*), an invasive exotic pasture grass (*Bromus inermis*), and a weedy shrub (*Symphoricarpos occidentalis*). Eight blocks, each containing native grass and two long established (equilibrium) invader clones, were studied in western N. Dakota. Species diversity (species > 50% constancy) fell from native (12) to shrub (5) to brome (3). Phenology of the types was essentially identical with first greening in March, maximum green in May, significant browning in July, and final browning in October.   Forage production (excluding roots and wood) rose from native (199) to shrub (204) to brome (259 gm.m-2), both on recently burned and long unburned sites. End-of-season protein content fell from native grass (1.3) and shrub (1.2) to brome (1.0%N). On all but recently burned sites, standing crop and structure (vertical and horizontal) rose from brome to native grass to shrub; such structure provides niche diversity for animals from insects to birds and undoubtedly affects their diversity. Summer soil temperature (15 cm) was slightly lower under shrubs than native grass or brome, probably due to interception of solar radiation by the canopy. July-August soil water stress (15cm) was less under brush and brome than under native grass; this may have been due to lesser inputs under grass (snow capture) or greater losses (soil temperature-induced evaporation or freer grass transpiration). Higher snow capture on brush sites (ie leaching) is probably responsible for reduction of conductivity (salinity) and pH on these sites.   One concludes 1) that different systems may favor different goals (eg diversity vs production), 2) that the reversibility of vegetation induced changes is uncertain (eg leaching, loss of diversity) and 3) that the value ($\pm$) of communities may vary according to the pattern and proportion of community types (eg feeding vs cover types) in a landscape.

EFFECTS OF PRESCRIBED FIRE ON INVASION OF NORTHERN MIXED-GRASS PRAIRIE IN LOSTWOOD NATIONAL WILDLIFE REFUGE.

JS Hartz-Rubin, T Weaver, CS Rubin, FG Giese. Contact Information: JSHR, 507-289-1614, Department of Biology, Rochester Community and Technical College, Rochester, MN 55904, Jennifer.Rubin@roch.edu

We measured the long-term effects of prescribed fire on plant invasion of mixed-grass prairie to provide a quantitative understanding of how fire management and planning in the northern Great Plains affects prairie vegetation. Two decades of prescribed fire management on National Wildlife Refuge (NWR) lands in northwestern North Dakota provided a unique opportunity to interpret long-ranging effects of fire on mixed-grass prairie habitat, in particular the widespread and abundant exotic grasses, smooth brome [(*Bromus inermis* Leyss.) and Kentucky bluegrass (*Poa pratensis* L.)], and native shrub [western snowberry (*Symphoricarpos occidentalis* Hook.)], which are of primary management concern. To do so, we compared plant communities with 0-6 prescribed fires in four separate habitats (bottom, north-slope, south-slope, and hilltop) at Lostwood NWR. The frequency and dominance of these and six other invasive species were measured with sub-plot sampling and transect methods.

Evidence for management effects was little. Fire tended to reduce invasiveness (e.g., frequency) of smooth brome on drier grazed site; Kentucky bluegrass and western snowberry tended to increase with more fire in grazed areas.

When data were pooled across habitat strata, there was no consistent change across habitats in the establishment (i.e., frequency) or cover (i.e., success) of smooth brome, Kentucky bluegrass, or western snowberry with an increasing burn number. The other six invasive species were too infrequent to support statistical statements. When data were pooled across both habitat strata and burn number, the cover of invasive species on burned areas was slightly lower than on unburned areas.

We conclude that while fire and grazing effects may exist, they are too slight to detect by comparing sites with different numbers of burns. Instead we need well-controlled experiments in which the effects of season and fire intensity are examined in replicated blocks in the major habitats, south- and north-slopes and bottoms.

EFFECTS OF PRESCRIBED FIRE ON INVASION OF NORTHERN MIXED-GRASS PRAIRIE IN DES LACS NATIONAL WILDLIFE REFUGE.

JS Hartz-Rubin, T Weaver, CS Rubin, FG Giese. Contact Information: JSHR, 507-289-1614, Department of Biology, Rochester Community and Technical College, Rochester, MN 55904, Jennifer.Rubin@roch.edu

We measured the long-term effects of prescribed fire on plant invasion of mixed-grass prairie, to provide a quantitative understanding of how fire management and planning in the northern Great Plains affects prairie vegetation. Two decades of prescribed fire management on National Wildlife Refuge (NWR) lands in northwestern North Dakota provided a unique opportunity to measure long-term effects of fire on weeds of mixed-grass prairie, in particular two widespread and abundant exotic grasses [smooth brome (*Bromus inermis* Leyss.) and Kentucky bluegrass (*Poa pratensis* L.)] and a native shrub [western snowberry (*Symphoricarpos occidentalis* Hook.)], which are of high management concern. To do so, we compared plant communities with 0-7 prescribed fires in four separate habitats (bottom, north/east-slope, south/west-slope, and hilltop/high plain) at Des Lacs NWR. The frequency and dominance of these and six other invasive species were measured with sub-plot sampling and transect methods.

Evidence for management effects was little.   Fire tended to reduce invasiveness (e.g., frequency) of smooth brome on moister ungrazed sites.

When data were pooled across habitat strata, there was no consistent change across habitats in the invasiveness (e.g., frequency) of smooth brome, Kentucky bluegrass, or western snowberry with increasing burn number; grazed and ungrazed areas showed similar patterns. The other six invasive species were too infrequent to support statistical statements. When data were pooled across both strata and burn number, the frequency of smooth brome appeared to increase with an increasing number of burns.

We conclude that while fire and grazing effects may exist, they are too slight to detect by comparing sites with different numbers of burns. Instead we need well-controlled experiments in which effects of season and fire intensity are examined in replicated blocks in the major habitats, south- and north-slopes and bottoms.