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CAN SHEEP CONTROL LEAFY SPURGE WITHOUT COMPROMISING EFFORTS TO RESTORE NATIVE PLANTS?

Eva S. Masin
The University of Montana

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By

Eva S. Masin

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Approved by:

Perry Brown, Associate Provost for Graduate Education

Graduate School

Dr. Cara R. Nelson, Chair

College of Forestry and Conservation

Dr. Donald J. Bedunah

College of Forestry and Conservation

Dr. Daniel T. Spencer

Department of Environmental Studies

Morgan T. Valliant, M.S.

City of Missoula Conservation Lands Manager

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Chairperson: Dr. Cara R. Nelson

This thesis includes two studies on the ecological effects of using sheep to control *Euphorbia esula* (leafy spurge). While sheep can effectively reduce *E. esula* when used as a long-term management strategy, little is known about their impacts on native plants. The efficacy of sheep grazing for restoration depends both on its potential for controlling undesirable plants and its ability to promote native species that provide key ecosystem goods and services. I investigated the effects of sheep grazing on native plants at both seed and mature-plant stages. To assess impacts on seedling establishment, I measured density of forb and graminoid seedlings in 15 grazed and 15 control (un-grazed) plots; after grazing, plots were treated with one of five experimental seeding treatments that varied by season and density of seed applied. To assess sheep impacts on abundance of mature plants, I measured change in percent stems grazed (pre- to post-grazing) of perennial forbs in 55 plots (including five controls) in an *E. esula* -invaded area with remnant native plants. Grazed plots had significantly fewer graminoid seedlings than un-grazed ones (28 vs 61/plot, respectively), but forb seedling density did not vary significantly. Mean change in percent stems grazed was higher for non-native than for native forbs (70% vs 23%, respectively), indicating that sheep preferentially grazed non-natives. However, sheep also consumed native forbs when they were abundant. Thus, appropriately timing grazing and careful monitoring of consumption is critical to reduce impacts on native plants.

I also conducted a pilot study of the role of sheep as dispersal vectors for plant seeds. I measured seedling germination rates in feces collected from sheep used for *E. esula* control. Density and species of germinants were recorded from pots with soil enriched with fecal samples from 13 time periods as well as control pots with only soil. A total of 125 seedlings germinated from the feces (80 forbs and 45 graminoids), including five non-native (three forbs, two graminoids) and two native (forb) species. Forb germination rates were highest in late summer samples, while graminoid rates were higher in early-summer and ones. Overall, sheep fecal dispersal favored non-native plants.

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Introduction

Across the globe, non-native invasive plants are a primary cause of degradation of grassland ecosystems (Pimentel et al. 2000; MacDougall and Turkington 2005; Sagoff 2011). In western North America, *Euphorbia esula* (leafy spurge) is one of the most damaging invasive species, infesting thousands of hectares of grasslands (Dewey and Anderson 2004). Primary adverse ecological impacts of *E. esula* invasion include reduced species diversity, loss of wildlife habitat and increased soil erosion (Beck 1994). In addition to ecological damage, invasion by *E. esula* directly affects local economies due to weed control costs, reduced livestock forage and loss of soil fertility (Leitch et al. 1984). Although total direct economic costs are difficult to estimate, *E. esula* has resulted in economic losses of over $30 million/yr in just the state of Montana alone. One increasingly popular method used to control non-native plants, such as *E. esula,* is domestic sheep grazing, which can be effective when used as part of an integrated, long-term management strategy (Landgraff et al. 1984; Olson and Wallander 1998; Bangsund et al. 2001). However, surprisingly little is known about the impacts of this practice on native plant communities (Olson and Wallander 1998; Seefeldt and McCoy 2003). Although the effect of sheep grazing has been documented for some native plants (e.g., McIntyre and Lavorel 1994; Stohlgren et al. 1998; Landsberg et al. 2002), it is unknown for most – including forbs and graminoid species often chosen for re-vegetation treatments. The efficacy of sheep grazing as a restoration tool depends on both its potential for controlling undesirable plants and its ability to promote native species that provide key ecosystem goods and services. I investigated the impact of sheep grazing on the establishment of native plants growing in *E. eusla* invaded grasslands in western Montana.

Although sheep will consume grasses, they have been documented to prefer forbs (Cook 1983) and to regularly consume *E. esula* (Olson and Lacey 1994). Sheep grazing will not eradicate *E. esula* but can minimize its spread and reduce large infestations over time. Effective control requires repeat grazing over as many as four years, if grazing is timed to remove vegetation early in the season (Popay and Field 1996). When sheep graze early in the plants' life cycle, the plants produce fewer flowers and seeds and, therefore, contribute fewer seeds to the soil seed bank. Grazing *E. esula*-infested areas takes advantage of low-cost, nutrient-rich food for sheep (Olson and Lacey 1994), while simultaneously reducing the extensive ecological damage caused by *E. esula*.

If reduction of above-ground biomass of *E. esula* is the sole management objective, sheep clearly can play a beneficial role. However, true ecosystem restoration requires the recovery of resilient native plant communities, not just eradication of a particular weed. The role of sheep in advancing this goal remains unclear. To date, studies that have investigated the efficacy of sheep grazing as a restoration tool have focused primarily on the ability of sheep to reduce target invasive plants (Landgraff et al. 1984; Lym 1998; Olson and Lacey 1994) or on their effects on crops (e.g., Kenney and Black 1984; Arnold 1987; Chapman et al. 2007) rather than the extent to which grazing promotes functional native ecosystems, including characteristic assemblages of native species. Because invasive-plant-control programs often involve seeding with native plant seeds in combination with long-term grazing, there is an immediate need for data on the sensitivity of plants that are used or being considered for inclusion in native seed mixes. For a limited number of native plants, information is available on palatability to and forage value for domestic sheep (e.g., Weaver and Hansen 1941; Dittberner and Olson 1983; Natural Resources Conservation Service 2009). However, data on many common native species is lacking. Furthermore, additional information is warranted, even for those native species for which there is data, because responses may vary by locality and plant community composition.

Sheep may have both positive and negative effects on native plants. In areas where sheep effectively reduce non-natives, native plants may benefit from reduced competition. However, heavy grazing and associated soil disturbance caused by sheep may decrease establishment of native plants, although effects may be mitigated in some cases by reducing grazing intensity (Eckert et al. 1986). Additionally, the absence of shade from neighboring vegetation in grazed areas may also limit successful seedling establishment (Edwards et al. 2005) and sheep may damage or kill native plants by preferentially grazing them, although some species are more susceptible to grazing than others (Diaz et al. 2001).

Sheep may be more likely to select one type of forage over another due to a combination of conditioning, differences among plants in nutrient status, or abundance. It is well known that sheep selection of forage is influenced by prior experience (Arnold 1987; Olson and Lacey 1994; Parsons et al. 1994). Thus, sheep can be conditioned to graze target species, such as *E. esula* (Olson et al. 1996). However, despite their propensity for conditioning, sheep tend to favor nutrient-rich foods over low-quality options, when given a choice (Westboy 1974; Villalba and Provenza 1999). Managers interested in maximizing both invasive plant control and optimal forage for sheep time their grazing programs to target plants at their peak flowering stage, when plant nutrient and water content is high (M. Valliant 2010, Missoula Parks and Recreation, Missoula, MT, personal communication). In areas where plants that sheep have been conditioned to graze are present or where other nutrient-rich forage is abundant, sheep will exhibit strong food preferences; however, in areas where choice forage is not available, they may act more as generalist herbivores (Schwartz and Ellis 1981) and consume any plants that are readily available. Because sheep can adjust their daily grazing substantially in response to the dietary choices in front of them (Chapman et al. 2007), they may disproportionally affect native plants in areas where these plants are more abundant than non-natives.

I investigated the impacts of free-grazing domestic sheep on establishment of seeded native plants and on established native forbs growing in *E. esula*-invaded native grasslands. The objective of the study was to provide land managers with information about the suitability of sheep grazing as a control method for *E. esula* when native plant recovery is a desired management objective. The specific research questions that were addressed are:

1) *Does sheep grazing affect establishment of seeded native forbs and graminoids in areas seeded for restoration? If so, do effects of sheep grazing vary with season or rate of seed application?*

2) *In leafy-spurge-invaded grasslands with remnant native vegetation, do sheep preferentially graze native or non-native plants and does pre-grazing cover affect consumption of native plants?*

Methods

Study Site ─ This study was conducted on the east side of Mount Jumbo, at the southern end of the Rattlesnake Mountains in western Montana. Predominant slopes in the study area range from ca. 35-45%, and soils range from gravelly loams to sandy silts (Natural Resources Conservation Service 2009). Elevation in the study area ranges from 1150-1250 m, and average annual precipitation is approximately 35 cm, although Mount Jumbo received nearly 41 cm of precipitation during the study time period in 2009 (National Oceanic and Atmospheric Administration 2009).

The study site is characterized by moderate-to-high levels of *E. esula* invasion, with pockets of relatively intact remnant native plant populations. *Euphorbia esula* is a highly aggressive invader that is among the most difficult noxious weeds to control. Early germination, rapid growth, high rates of reproduction, seed longevity, and an extensive root system give it a competitive advantage over native plants. Seedlings and shoots from over wintering *E. esula* are often the first plants to emerge in spring (Kott 2006). Once seeds germinate, vegetative buds may appear within seven days (Selleck et al. 1962) and flowers within just three weeks (Kott 2006). Individual *E. esula* stems produce an average of 140 seeds, which may remain viable in the soil for more than eight years (Wicks and Derscheid 1964). Once established, *E. esula* spreads rapidly by its roots, which contain numerous below-ground buds that are capable of producing new shoots at multiple points along any root segment; roots of a single plant can spread up to five m in diameter in a single year (Selleck et al. 1962) and can penetrate up to 12 m deep allowing it to survive via a large nutrient reserve (Kott 2006). The extensive root system makes it difficult to control *E. esula* solely with chemical or mechanical treatments; instead, effective *E. esula* control requires long-term, integrated management approaches.

In addition to *E. esula*, more than 20 broad-leaved herbaceous plants (forbs), both native and non-native, occur in the study area. Embedded within E. esula infested areas are patches of remnant plant communities in which natives dominate but non-native forbs still account for a substantial component of total herbaceous plant cover. The dominant native plants are bunchgrasses, including *Agropyron spicatum* (bluebunch wheatgrass), *Poa secunda* (Sandberg bluegrass), *Koeleria macrantha* (Junegrass), and *Festuca idahoensis* (Idaho fescue). Native forbs that commonly occur at the study site include *Aster falcatus* (prairie aster), *Astragalus* spp. (milkvetch), *Heterotheca villosa* (hairy golden aster), *Lupinus sericeus* (silky lupine), *Achillea millefolium* (yarrow), *Gaillardia aristata* (blanket flower), *Artemisia frigida* (fringe cup sage) and *Cirsium undulatum* (wavy leaved thistle). Commonly occurring non-native plants include *E. esula, Potentilla recta* (sulfur cinquefoil) and *Tragopogon dubius* (yellow salsify).

Euphorbia esula infested areas on Mt. Jumbo are grazed annually by ca. 400 lambs and ewes and ca. five goats. Because 99% of the grazing animals are sheep, hereafter, I refer to grazing as sheep grazing, despite the fact that some grazing is by goats. Grazing animals are allowed to roam freely and generally forage in small, dispersed groups.

Experimental Treatments and Field Methods — To assess the effect of grazing on seedling establishment (*Question 1*), seedling density was measured in permanent plots that are part of a long-term grazing study designed by Morgan Valliant, Conservation Lands Manager at Missoula Parks and Recreation. The study used a two-factor design (grazing and seeding) with two levels of grazing (grazed and not grazed) and five levels of seeding that varied by season and rate of application: 1) spring/fall-seeding high-application rate (s/f:H; 44.84 kg/ha — half applied in April and half in October 2009, 2) spring/fall/spring-seeding medium-application rate (s/f/s:M; 28.05 kg/ha — 11.22 kg/ha applied in April and in October 2009, and 5.61 kg/ha applied in April 2010), 3) fall-only-seeding high-application rate (f:H; 44.84 kg/ha — all applied in October 2009, 4) fall-only-seeding low-application rate (f:L; 22.44 kg/ha — all applied in October 2009), and 5) not seeded. Each of these five experimental conditions was replicated in six randomly selected 5-m² plots (*n*= 30). All seeded plots were hand broadcasted with a mixture of five native forbs and five native grasses (Table 1) with seed from two local suppliers: Wind River Seed (Manderson, Wyoming) and Native Ideals (Arlee, Montana). Following initial spring seeding treatments in April of 2009, sheep grazed 15 plots (*n*= 3 for each of five seeding treatments) for approximately 4 weeks from June 1 to July 14, 2009. The additional 15 plots (*n*= 3 for each of five seeding treatments) were protected from grazing by a permanent fenced enclosure. In October 2009, following summer sheep grazing, all treated plots were seeded. Plots that received the spring/fall/spring treatment were seeded again in April of 2010.

In June 2010, prior to the 2010 grazing season, I counted all graminoid and forb seedlings (< 5-cm tall) present within each of 16 50 x 50-cm sub-plots located within each 5-m² plot. Seedlings germinating from natural sources could not be discriminated from those establishing from the seeding treatments; thus, both were included in density measurements.

To assess whether sheep preferentially graze native or non-native plants and if pre-grazing cover affects consumption of native plants (*Question* 2), I measured pre- and post-grazing abundance of forbs in vegetation changes in pockets of mixed native/non-native vegetation communities. In May 2010, prior to sheep grazing, I randomly located 60 2-m-diameter circular study plots. Plots were rejected if the total percent cover of *E. eusla* was greater than 50% or if fewer than three native perennial forbs were present. Within each plot, I measured total percent cover of native and non-native forbs using the following cover classes: 0- ≤1%, >1 - ≤5%, >5 - ≤15%, >15% - ≤25%, >25 - ≤35%, >35 - ≤45%, >45 - ≤55%, >55 - ≤65% (no species occurred at > 65% cover). In addition, I also recorded density of perennial and biennial forb stems by species in one randomly selected quadrant within each plot. Plants with multiple branching stems (basal rosettes) were counted as one stem if the branching point was visible above the surface of the ground. In order to minimize counting errors in quadrants with >50 individual forbs, I rounded stem counts to the nearest multiple of 10.

Prior to introducing sheep to the study site, sheep grazed an area adjacent to the study plots that was heavily infested with *E. esula* for approximately one week. After this conditioning period, 50 plots within the study area were available for grazing over approximately five weeks (June 9 to July 19, 2010). The remaining 10 plots were established as controls and remained protected from grazing by a 1.3–m-high low-tension electric fence that was intended to exclude sheep and goats, but not deer. During the five-week grazing period, I monitored the small, dispersed bands of grazing sheep weekly to ensure that plots were grazed. I also checked control plots to determine if the fence was restricting access. Unfortunately, five of 10 control plots were compromised by a single goat who managed to get through the fence on July 2, 2010. These five plots were excluded from analyses.

After sheep had grazed the study area for one week, I estimated the percent of forb stems grazed by species in each of the 55 2-m-diameter circular plots. For the next four weeks, I conducted mid-grazing-period assessments on a random subset of the 55 total plots (including the five un-grazed control plots) on a weekly basis. Number of plots sampled per week varied: n= 11 for week two; n= 18 for week three; and n= 21 for week four, with some plots sampled during more than one sampling period. At each plot selected for weekly monitoring, I estimated the percent of forb stems grazed by species using the following categories: 0- ≤1%, >1 - ≤5%, >5 - ≤15%, >15% - ≤25%, >25 - ≤35%, >35 - ≤45%, >45 - ≤55%, >55 - ≤65%, >65 - ≤75%, >75 - ≤85%, >85 - ≤95%, >95 - ≤100%. At the end of the grazing period, grazed and un-grazed forb stems were recounted by species in each randomly selected quadrant of the 2-m-diameter circular plots.

Species nomenclature follows Lackschewitz (1991) for forbs and Lavin and Seibert (2011) for graminoids.

Statistical analyses — Prior to analyses, I assessed normality of all response variables using graphical and numerical methods. Because my response variables were not normally distributed, I used non-parametric analyses.

To assess the effect of grazing on seedling establishment (Question 1), I compared seedling density in grazed versus un-grazed plots using Mann Whitney tests (n=30) (Ott and Longnecker 2010), with separate tests for each of three response variable: 1) density of forb seedlings, 2) density of graminoid seedlings, and 3) density of seedlings of each species with germinants on ≥20% of plots. To assess the effect of seeding treatment on seedling establishment, I compared seedling density among the five seeding treatments using Kruskal Wallis tests (n= 30) (Ott and Longnecker 2010), with separate tests for each of the same three response variables (above). I conducted separate test for all plots, grazed plots and un-grazed plots.

To address whether sheep preferentially graze native versus non-native forbs, I first assessed background changes (i.e. changes not due to grazing) in percent stems grazed and stem density. I did this by testing for differences between the pre-grazing period assessment and the post-grazing-period assessment for each response variable (stem density and percent stems grazed for native and non-native forbs) in control plots (i.e. plots not grazed) using Wilcoxin signed rank tests (n= 5; control plots only), with separate tests for each response variable.

To assess the effect of grazing outside of the control plots (i.e. in the plots that sheep were allowed to graze), we used three measures of response for each of two vegetation groups (native and non-native forb): 1) post-treatment stems grazed, 2) change (pre- to post-treatment) in percent stems grazed, and 3) change in stem density. For change in percent stems grazed, I first calculated percent stems grazed for native and non-native forb groups both pre- and post-treatment, and then calculated changes between the two measurement periods for each group. I also calculated change in stem density between pre- and post-grazing measurements. For all calculations, I only included data for common forb species (those that occurred at ≥15% pre-treatment frequency). I tested for differences in response (separate tests for each of the three response variables listed above) between native and non-native forbs using Kruskal Wallis tests (n =50; grazed plots only, excluding controls). I used Spearman rank correlations (n= 50) (Ott and Longnecker 2010) to assess the relationship between each response variable (post-treatment stems grazed, change in percent stems grazed, and change in stem density, for both native and non-native forbs) and pre-treatment percent cover of native or non-native forbs. Finally, temporal trends in percent stems grazed were assessed graphically for common forbs.

All statistical analyses were conducted using SPSS 15.0 (SPSS, 2009). An alpha level (p) of 0.05 was used as the criterion for statistical significance.

Results

Does sheep grazing affect establishment of seeded native forbs and grasses? (Question 1)—Of the five forbs seeded on the study plots, only *G. aristata* seedlings occurred frequently (in more than 20% of all plots) and were common on both grazed and un-grazed control plots (Table 2). Two species (*A. millefolium* and *P. procerus*) occurred only in seeded plots, and the remaining seeded species (*A. frigida* and *M. fistulosa)* did not have seedlings on any plots. All five of the seeded grasses (Table 1) were recorded on more than 20% of the total plots, but only three (*A. spicatum, K. macrantha* and *P. secunda*) occurred at above 20% frequency on both grazed and un-grazed controls (Table 2). Seedlings from all seeded graminoid species except *F. idahoensis* occurred in both seeded and un-seeded control plots; *F. idahoensis* occurred only in seeded plots.

The density of seeded forbs did not differ significantly between grazed and un-grazed plots (6/m² and 11/m², respectively; z = -0.956, p = 0.367, df = 29; Fig. 1). However, there were significantly fewer graminoid seedlings in grazed versus un-grazed plots (83/m², vs 184/m², respectively; z = -2.609, p = 0.009, df = 29; Fig. 1). I did not detect a significant difference in seedling density between grazed and un-grazed plots for *G. aristata* (5/m² and 10/m², respectively; z = -0.387, p = 0.717, df = 29)—the one forb that was common enough for testing (i.e. > 20% of plots had germinants). However, I did find significant differences in seedling density between grazed and un-grazed plots for two of the five graminoid species tested: *K. macrantha* (10/m² and 107/m², respectively; z = -3.744, p = 0.000, df = 29) and *S. comata* (0.2/m² and 48/m², respectively; z = -4.036, p = 0.000, df = 29). Significant differences were not detected for the other 3 graminoids: *P. secunda* (71/m² and 20/m², respectively; z = -0.168, p = 0.870, df = 29), *F. idahoensis* (0.2/m² and 6/m², respectively; z = -2.238, p = 0.098, df = 29) and *A. spicatum* (0.8/m² and 1/m², respectively; z = -0.149, p = 0.935, df = 29).

Seeding treatment did not significantly affect density of seedlings of either forbs (h = 8.643, p = 0.071, df = 29) or graminoids (h = 5.794, p = 0.215, df = 29) when assessed across all plots (i.e. both grazed and un-grazed plots). There were also no among-seeding-treatment differences in seedling density when tests were done by individual treatments (grazed plots only — forbs [h = 4.076, p = 0.396, df = 14] and graminoids [h = 5.826, p = 0.212, df = 14]; un-grazed plots only — forbs [h = 6.642, p = 0.167, df = 14] and graminoids [h= 1.607, p = 0.878, df= 14]) (Fig. 2). Although the trend was not significant, forb seedling density was highest in the s/f H and s/f/s M treatments for grazed plots and in the f H, s/f H and s/f/s M treatments for un-grazed plots (Fig. 2, A), and graminoid seedling density was highest for fall and spring/fall-high-application-rate treatments for grazed plots (Fig. 2, B). For un-grazed plots, graminoid seedling densities were consistent across all treatments, including the control plots which were not seeded (Fig. 2, B).

In leafy-spurge-invaded grasslands with remnant native vegetation, do sheep preferentially graze native or non-native plants and does pre-grazing cover affect consumption of native plants (Question 2)? — I found a total of 25 perennial forbs on study plots (Table 3). Of these, only 10 (seven natives and three non-natives) met the criterion for analysis (occurred at >15% pre-treatment frequency). I found evidence of grazing on five of seven common native forbs (*A. falcatus, A. millefolium, G. aristata*, *Astragalus* spp. and *L. sericeus*); the remaining two, *H. villosa* and *C. undulatum,* were not observed to have been grazed (Table 3). All three of the common non-native forbs (*E. esula*, *P. recta* and *T. dubius*) were grazed (Table 3). For one of these (*T. dubius*), I observed trace amounts of grazing pre-treatment (likely by deer). Mean total pre-treatment stem density was considerably lower for the seven common native species than for the three common non-native species (23/m² vs 59/m², respectively). Fifteen less common (occurred at <15% pre-treatment frequency) forbs were also observed on study plots — 10 were native and five were non-native. Two of these less common natives (*Erigeron pumilis* and *Lomatium* spp.) and four non-natives (*Centaurea maculosa, Linaria dalmatica, Sisymbrium* spp. and *Taraxacum officinale)* were grazed (Table 3).

In the un-grazed control plots, there were no significant differences between pre- and post-treatment measurements of percent stems grazed for total native (z = 0.000, p = 1.000, df = 4) or total non-native forbs (z = 0.000, p = 1.000, df = 4). Additionally, no significant differences were detected between pre- and post-grazing measurements of stem density for total native (z = -0.674, p =0.500, df = 4) or total non-native forbs (z = -0.135, p = 0.893, df = 4).

In plots where sheep were allowed to graze, I found a significant difference between vegetation groups (native vs non-native forbs) in two of my measures of response: stems grazed (z= -2.539, p = 0.011, df = 49; Fig. 3, A) and change in percent stems grazed (z = -4.182, p = 0.000, df = 4 9; Fig. 3, B). I did not find significant differences between natives and non-natives in the third measure of response: change in stem density (z = -0.743, p = 0.457, df = 49).

Pre-treatment percent cover of *native* forbs was significantly correlated with both native stems grazed post-treatment (r_s = 0.311, p = 0.028; Fig. 4, A) and non-native stems grazed post-treatment (r_s = 0.547, p = 0.000; Fig. 4, B). No significant correlations were found between pre-treatment percent cover of native forbs and change in percent stems grazed or change in stem density for either native or non-native forbs.

Change in percent *native* stems grazed was weakly negatively correlated with pre-treatment percent cover of *non-native* forbs (r_s = -0.274, p = 0.054; Fig. 5, A). However, no significant correlation was found between change in percent *non-native* stems grazed and pre-treatment percent cover of *non-native* forbs (Fig. 5, B). Similarly, neither of the other two measures of response (stems grazed post treatment and changes in stem density) were significantly correlated with pre-treatment percent cover of either non-native or native forbs.

In plots where sheep were allowed to graze, trends in percent stems grazed over time varied by species (Fig 6). For *E. esula* and *P. recta,* percent stems grazed increased until week two and then remained constant through week four (Fig. 6). For *A. falcatus,* percent stems grazed increased during weeks one and two, then declined in week three and increased again during the fourth and final week of the grazing period. *Gaillardia aristata* and *Astragalus* spp. had < 10% stems grazed through week two, after which percent stems graze increased through week four (Fig. 6). *Lupinus sericeus* and *A. millefolium* had low to no percent stems grazed throughout the grazing period (Fig. 6).

Discussion

Despite increasing interest in using sheep as a management tool for controlling noxious weeds (Landgraff et al. 1984; Olson and Wallander 1998; Bangsund et al. 2001), there has been little emphasis on the ecological impacts of this practice on non-target native plants. Although I found that sheep preferred common non-native forbs (*E. esula* and *P. recta*) over native ones, my results also indicate that sheep grazing may adversely affect re-vegetation programs by reducing germination and establishment of graminoids and by causing damage to non-target native plants growing adjacent to invasive species that are targeted for weed control. In addition, sheep may spread the seed of invasive plants as they move between grazing areas (Appendix 1). Although my research has important implications for restoration of native grasslands, the absence of replicate sites and the short study duration (one year) limit the scope of inference.

Does sheep grazing affect establishment of seeded native forbs and grasses? (Question 1) —Densities of seedlings of seeded forbs were relatively low overall within our study plots, especially when compared to graminoids. Although seedlings from each of the five seeded graminoid species established successfully on more than 20% of the study plots, seedlings of only one seeded forb (*G. aristata*) occurred on more than 20% of plots. Seedlings of two forbs, *Artemisia frigida* and *M. fistulosa,* were not detected on any study plots, although they were found within the study area. Low forb germination rates on my sites may be due to poor soil conditions, which frequently results in rapid drying of the soil (Bleak et al. 1965). However, forb germination rates are frequently reported to be low after seeding; small seeded species (such as most forbs) have low establishment rates due to low seed mass which may reduce germination rates or result in small seedlings with reduced vigor (Gross 1984; Zhang and Maun 1993). Only one, *M. fistulosa*, of the five forb species on my sites was observed to have low seedling viability (< 60%) based on germination trials (M. Valliant 2010, personal communication); however, it is possible that seedlings germinated and then failed to establish. My results are consistent with those of Tyser et al. (1998), who found that native forb abundance did not increase with seeding in a fescue grassland ecosystem following three separate seeding treatments with a native graminoid-forb seed mix.

Low forb seedling density overall reduced my ability to detect affects of sheep grazing on forb establishment. However, I did find that sheep grazing prior to seeding reduced total graminoid establishment. The trend for lower total graminoid seedling densities in grazed compared to un-grazed plots may be driven by lower cover of understory plants where grazing occurs, and subsequently higher rates of seedling exposure to direct sunlight; bare soil without the shade of plant cover has been shown to limit successful establishment of direct seeded forage plants in grazed pastures (Edwards et al. 2005). Although prior grazing had a negative overall effect on graminoid seedling density, responses varied by species. *Koeleria macrantha* and *S. comata* had lower seedling density in areas that had been grazed than in the un-grazed controls. However, density of *P. secunda* seedlings did not vary between previously grazed and un-grazed areas. The hardy root systems of *P. secunda* may explain why this species established more successfully than did *K. macrantha* or *S. comata* in grazed areas. *Poa secunda* seedlings have extensive, coarse, fibrous roots that may allow it to survive disturbance caused by grazing and trampling (Majerus et al. 2009). Thus this grass might be particularly well suited for seeding in areas subjected to periodic grazing.

Seeding appeared to be less important for graminoids than for forbs on my sites. In the un-grazed control area, total seedling densities was relatively high in both seeded and unseeded plots and, for four of five graminoids included in the seed mix (*A. spicatum, K. macrantha, P. secunda* and *S. comata)*, germination rates did not differ between seeded and un-seeded plots. The only graminoid included in our tests that did not establish well in unseeded plots was *F. idahoensis.* In contrast, forbs seedling establishment was poor overall. Seeding treatments facilitated establishment for two of the seeded species (*Achillea millefolium* and *P. procerus*) that occurred only in seeded plots. Thus, seed application may be necessary for establishment of these forbs on my sites. Of the other three seeded forb species, *G. aristata* and *A. frigida* established on both seeded and un-seeded plots, while *M. fistulosa* did not establish successfully within either treatment.

Climatic conditions during the study period may have had an effect on seedling establishment rates. High precipitation during the growing season in 2009, during and directly following initial seeding treatments, may have allowed for higher than average establishment from both natural and artificial sources across all treatments. Thus, inference from my results may be best applied to high precipitation years or moist sites; lower seeding success may occur in years of average or low precipitation.

In leafy-spurge-invaded grasslands with remnant native vegetation, do sheep preferentially graze native or non-native plants and does pre-grazing cover affect consumption of native plants? (Question 2) — Prior to grazing, vegetation composition within un-grazed controls was similar to that of the areas which were grazed by sheep. Because I did not detect any differences between pre-and post-treatment measurements of stems grazed or percent stems grazed in un-grazed controls, observed changes in stems grazed and percent stems grazed in plots where sheep were allowed to graze are attributable to the effects of grazing.

Non-native forbs were the preferred forage type of sheep grazing on Mt. Jumbo: sheep grazed more non-native than native forb stems throughout the grazing season. In particular, the three most common non-natives (*E. esula, P. recta* and *T. dubius*) were frequently grazed, probably because they were all highly abundant. Stem densities of *E. esula* were higher than those of any other forb species, and *P. recta* had higher stem densities than all other common native forbs except *A. falcatus* and *H. villosa.* Although there is ample evidence that *E. esula* is not only palatable but also provides nutrient rich forage for sheep (Olson and Lacey 1994), there was no previously published information regarding palatability or grazing use of *P. recta.* My findings suggest that sheep may be effective in removing *P. recta* plants in addition to *E. esula.* In addition, all four of the less common non-native forbs found on the study plots (*C. maculosa, L. dalmatica, Sisymbrium* spp. and *T. officinale*) were palatable to sheep; grazing had been previously documented for all of these species (Natural Resources Conservation Service 2009; K. Launchbaugh 2001; Dittberner and Olson 1983; McInnis and Vavra 1986) except *L. dalmatica*, a less common species that was also grazed regularly. However, these less common non-native plants were not a regular component of sheep diets, probably due to their lesser availability.

Sheep may have selected *E. esula* over native forbs due to conditioning or to its high nutrient content. On Mount Jumbo, sheep were conditioned to consume *E. esula* -during a period of exposure to an adjacent heavily infested area before being moved to the study area. There is also some evidence that the type and amount of forage grazed by sheep on Mount Jumbo varies with season and with flowering development (G. Hirschenberger 2010, Bureau of Land Management [retired], Missoula, MT, personal communication). The sheep grazing program on Mt. Jumbo is timed to target leafy spurge at its peak flowering and nutrient content stage, which is after many common native plants have flowered (M. Valliant 2010, personal communication).

However, the fact that sheep did consume native plants where these plants were abundant supports the notion that sheep forage choices can be driven by plant abundance rather than conditioning or plant nutrient content. For both native and non-native forbs, stems grazed post-treatment was positively correlated with pre-grazing abundance of *native* forbs; thus, grazing use of both types of forage increased with increasing native vegetation cover. This suggests that not only were sheep on my study plots were more likely to graze plots where native plants were common, but also that they were less likely to exhibit a preference for leafy spurge where natives were readily available. In contrast, grazing pressure on natives was somewhat negatively correlated with pre-grazing abundance of *non-natives*; indicating that sheep were less likely to graze natives in areas where non-native forage was widely available. These findings indicate that native plants growing in intact communities are more likely to be impacted by sheep grazing than are those growing within *E. esula* invaded areas.

Despite widespread interest in sheep grazing as a restoration tool, there is only limited information on palatability of many common native plants that restoration projects aim to increase. I observed sheep grazing on seven (41%) of the 17 native forbs on my sites. My results confirmed published accounts that *A. millefolium* has limited palatability to sheep (Dittberner and Olson 1983) but that *A. falcatus Astragalus* spp. and *Lomatium* spp. are preferred forage for sheep (Weaver and Hansen 1941; Soil Conservation Service 1982; Natural Resources Conservation Service 2009). I found that although sheep readily grazed all *A. falcatus, Astragalus*.and *Lomatium* plants, they often only grazed the tips of *A. millefolium* plants, despite the fact that this species was abundant. For the three other native plants that were grazed on my sites, information on palatability and grazing tolerance was not available prior to initiating my study: only anecdotal information was available for *L. sericeus* and *G. aristata* (G. Hirschenberger 2010, personal communication) and no information was available for *E. pumilis*. Therefore, despite small sample sizes, my investigation is the first to address non-target impacts of managed grazing programs on these plants. I found strong evidence that *Lupinus sericeus* and *G. aristata* are susceptible to grazing; both were both common on my sites and frequently consumed by sheep. These findings are consistent with anecdotal accounts (G. Hirschenberger 2010, personal communication). My results are less conclusive for *E. pumilis*. This plant was found infrequently on my sites but did experience low levels of grazing; it is unclear whether the observed low level of grazing was driven by low abundance, low palatability, or a combination of the two.

No grazing use was observed for 10 (59%) of the 17 native forbs which occurred on my study sites. Palatability information was available for five of these un-grazed native forbs: *Antennaria* spp.*, A. frigida, D. bicolor, H. annuus* and *H. villosa.* My results confirmed published accounts that *Antennaria* spp., *A. frigida* and *H. villosa* are undesirable forage for sheep (Weaver and Hansen 1941; Lauenroth et al. 1978; Natural Resources Conservation Service 2009). However, although *D. bicolor* and *H. annuus* have been reported to be fair forage for sheep (Dittberner and Olson 1983), neither was grazed at my study sites, possibly due to their low abundance. Information on palatability to sheep was not available for the five remaining un-grazed forbs on my study sites: *A. holboellii, C. undulatum, M. fistulosa, Penstemon* spp. and *P. patagonica.* Of these, only *C. undulatum* was widely available for forage, suggesting that this species may be resistant to sheep grazing.

My findings emphasize the importance of considering pre-grazing plant community composition when developing sheep grazing management plans for restoration. Kenney and Black (1984) found that sheep preferred to graze areas in which the forage type allowed for the highest rate of consumption over time. *Euphorbia- esula*-dominated areas provided sheep with dense forage, thus enabling them to fulfill their dietary requirements efficiently (Arnold 1987). My findings support the concept that ruminant livestock can adjust their daily grazing substantially in response to the dietary choices in front of them (Chapman et al. 2007), which in turn suggests that increased availability of native forage (resulting from successful restoration efforts) could increase the potential for negative impacts to natives growing in managed areas. However, with adequate monitoring and by carefully selecting grazing time periods, managers may be able to simultaneously control target non-native plants and successfully mitigate damage to desirable native species. Grazing of non-native forbs (primarily *E. esula* and *P. recta*) peaked by the third week of grazing when most of the available forage had been utilized. Grazing of two native forbs, *G. aristata* and *Astragalus* spp., increased only at the end of the grazing period, suggesting that sheep impacts to native vegetation could have been reduced by moving sheep immediately after peak use of *E. esula* was achieved. The decline in density of *A. falcatus* stems grazed in week two is probably a false trend, due to the combination of small sample sizes and the random selection of plots sampled during the second week of grazing.

Conclusions— Given increasing excitement about the potential for including sheep in integrated weed control programs for restoration, it is important to consider how grazing can be regulated in order to promote the establishment of desirable native species while reducing *E. esula*. Land managers using sheep to control weeds in mixed non-native/native vegetation communities should use careful monitoring to ensure that sheep do not cause unnecessary damage to native species once target weed removal levels are reached. Limiting grazing in native-dominated vegetation communities and moving sheep swiftly once target weed removal levels are reached could improve restoration outcomes in managed areas. Additionally, minimizing prior grazing use of seeded areas or reducing grazing intensity at key times of year could promote establishment of seeded grasses. While my findings elucidate short-term effects of sheep grazing on seedling establishment and on mature perennial forbs, further research and long-term monitoring is necessary to determine the efficacy and ecological impacts of sheep grazing in mixed native/non-native vegetation communities within *E. esula* invaded areas.

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Tables

Table 1. Scientific and common names of forbs and graminoids included in the seed mix applied to study plots and rate of application (g/m^2) for high (total of 44.84 kg/ha), medium (28.05 kg/ha) and low (22.42 kg/ha) treatments.

		High	Medium	Low
Scientific name	Common name	g/m^2	g/m^2	g/m^2
FORBS				
Gaillardia aristata	Blanket flower	3.36	2.10	1.68
Achillea millefolium	Yarrow	0.06	0.04	0.03
Artemisia frigida	Fringed sage	0.06	0.04	0.03
Monarda fistulosa	Bergamot	0.11	0.07	0.06
Penstemon procerus	Little flower penstemon	0.06	0.04	0.03
GRAMINOIDS				
Agropyron spicatum	Bluebunch wheatgrass	10.09	6.31	5.04
Festuca idahoensis	Idaho fescue	2.24	1.40	1.12
Stipa comata	Needle and thread grass	5.04	3.15	2.52
Poa secunda	Sandberg's bluegrass	1.12	0.70	0.56
Koeleria macrantha	Junegrass	0.28	0.18	0.14

Table 2. Scientific and common names of species of forbs and graminoids included in the seed mix and their frequency (% of plots) in grazed and un-grazed plots.

Scientific name	Common name	Grazed (%)	Un-grazed (%)
FORBS			
Gaillardia aristata	Blanket flower	67	86
Penstemon procerus	Little penstemon	13	0
Achillea millefolium	Yarrow	7	7
Artemisia frigida	Fringed sage	0	0
Monarda fistulosa	Bergamot	0	0
GRAMINOIDS			
Poa secunda	Sandberg's bluegrass	53	86
Koeleria macrantha	Junegrass	27	86
Agropyron spicatum	Bluebunch wheatgrass	33	27
Stipa comata	Needle and thread grass	7	60
Festuca idahoensis	Idaho fescue	7	40

Table 3. Scientific and common names, origin (native or non-native) [1], pre-treatment frequency (% of plots where present), and post-treatment status (grazed or un-grazed) of perennial forbs found on study plots.

Species	Common name	Origin	Frequency (%)	Status
Achillea millefolium	Yarrow	Native	25	Grazed
Antennaria spp.	Pussey toes	Native	1	Un-grazed
Arabis holboellii	Rockcress	Native	1	Un-grazed
Aster falcatus	Prarie Aster	Native	55	Grazed
Astragalus spp.	Milk vetch	Native	17	Grazed
Artemisia frigida	Fringe sage	Native	13	Un-grazed
Cirsium undulatum	Wavyleaf thistle	Native	17	Un-grazed
Delphinium bicolor	Delphinium	Native	5	Un-grazed
Erigeron pumilis	Daisy fleabane	Native	7	Grazed
Gaillardia aristata	Blanket flower	Native	17	Grazed
Helianthus annuus	Wild sunflower	Native	1	Un-grazed
Heterotheca villosa	Golden aster	Native	63	Un-grazed
Lomatium ssp.	Desert parsley	Native	4	Grazed
Lupinus sericeus	Silky lupine	Native	25	Grazed
Monarda fistulosa	Bergamot	Native	1	Un-grazed
Penstemon spp.	Penstemon	Native	1	Un-grazed
Plantago patagonica	Plantain	Native	3	Un-grazed
Centaurea maculosa	Knapweed	Non-native	3	Grazed
Cirsium vulgare	Bull thistle	Non-native	1	Un-grazed
Euphorbia esula	Leafy spurge	Non-native	78	Grazed

Table 3, continued.

Species		Origin)	Frequency (%)	Status
Linaria dalmatica	Dalmatian toadflax	Non-native	2	Grazed
Potentilla recta	Sulfur cinquefoil	Non-native	40	Grazed
Taraxacum officinale	Dandelion	Non-native	13	Grazed
Tragopogon dubius	Yellow salsify	Non-native	32	Grazed
Sisymbrium spp.	Tumble mustard	Non-native	2	Grazed

[1]Natural Resources Conservation Service, 2012

Figure Captions

Fig. 1. Mean (+/- 1 standard error) density of forbs and graminoids in grazed (black bars) and un-grazed (grey bars) plots.

Fig. 2. Mean (+/- 1 standard error) density of forbs (A) and graminoids (B) by experimental seeding treatment (fall-only-seeding high-application rate [f:H], fall-only-seeding low-application rate [f:L], spring/fall-seeding high-application rate [s/f:H]; spring/fall/spring-seeding medium-application rate [s/f/s:M], and unseeded control [C]) in grazed (black bars) and un-grazed (grey bars) plots.

Fig. 3. Mean (+/- 1 standard error) number of stems grazed post-treatment (A) and mean change in percent stems grazed pre-to-post treatment (B) for native (black bars) and non-native (grey bars) forbs.

Fig. 4. Relationship between density of stems grazed post-treatment and pre-grazing percent cover of native forbs, for native (A) and non-native (B) forbs.

Fig. 5. Relationship between change in percent stems grazed post-treatment and pre-grazing percent cover of native forbs, for native (A) and non-native (B) forbs.

Fig. 6. Trend (pre-grazing to week 4 of grazing) in estimated percent stems grazed for common forbs that were grazed: *Euphorbia esula, Potentilla recta, Aster falcatus, Gaillardia aristata*, Astragalus* spp.*, *Lupinus sericeus,* and *Achillea millefolium*. *Tragopogon dubius* is not shown because only trace amounts of this species were grazed. **Gaillardia aristata* and *Astragalus* spp. have the same trace style because they follow the same trajectory.

Fig. 1

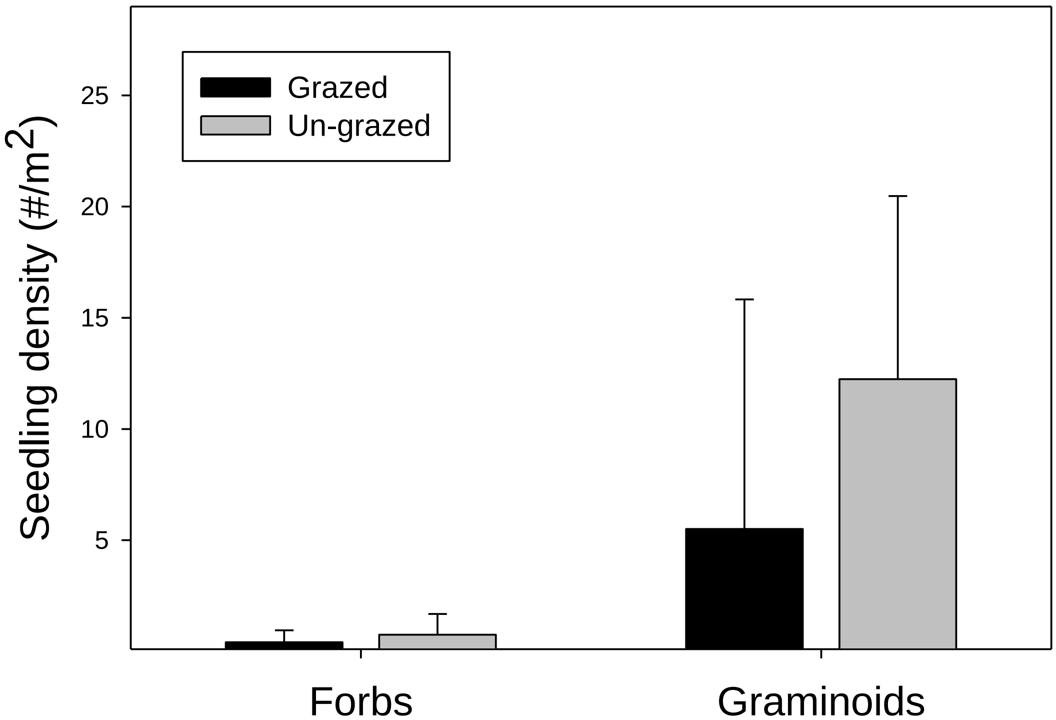

Grazed
Un-grazed
Seedling density (#/m2)
25
20
15
10
5
Forbs
Graminoids

Fig. 2

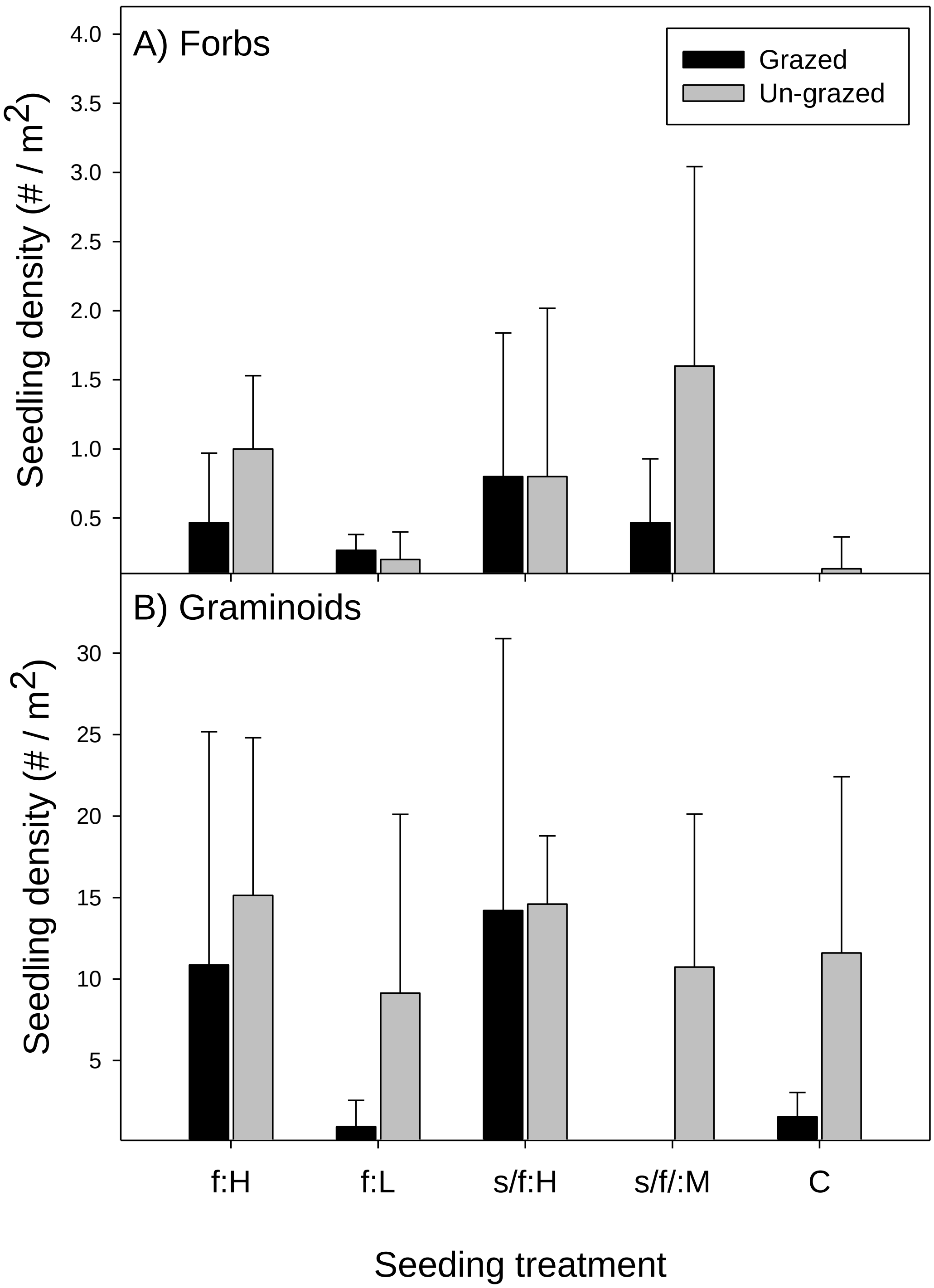

A) Forbs
Grazed
Un-grazed
Seedling density (# / m2)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
B) Graminoids
30
25
20
15
10
5
f:H
f:L
s/f:H
s/f/:M
C
Seeding treatment

Fig. 3

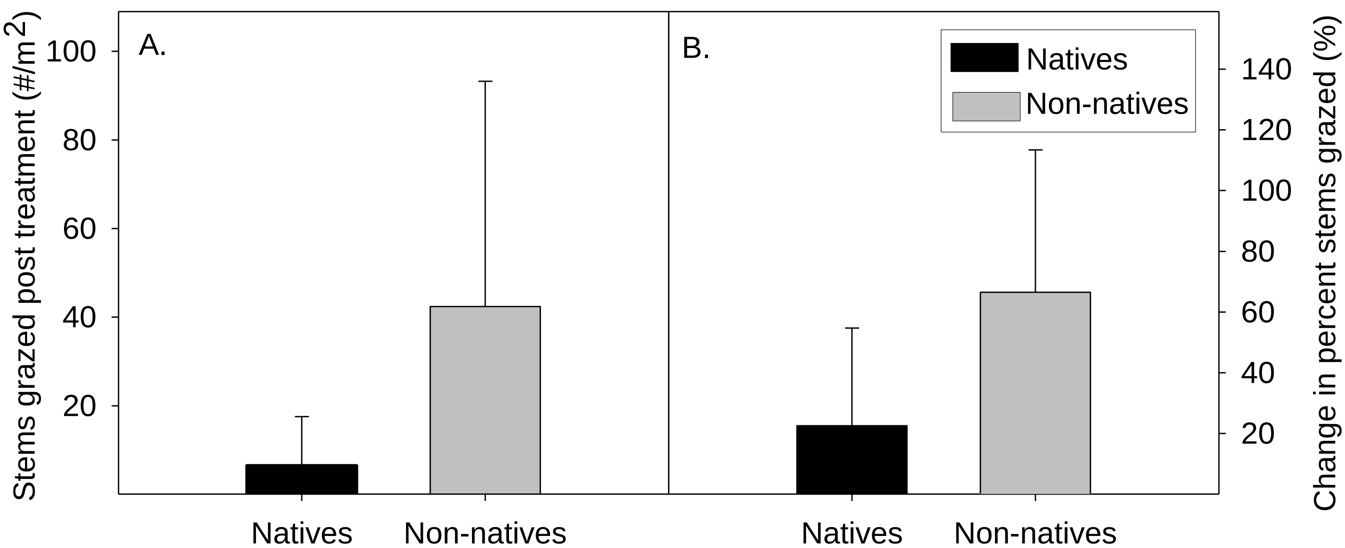

Stems grazed post treatment (#/m2)
100
80
60
40
20
A.
B.
Natives
Non-natives
140
120
100
80
60
40
20
Change in percent stems grazed (%)
Natives
Non-natives
Natives
Non-natives

Fig. 4

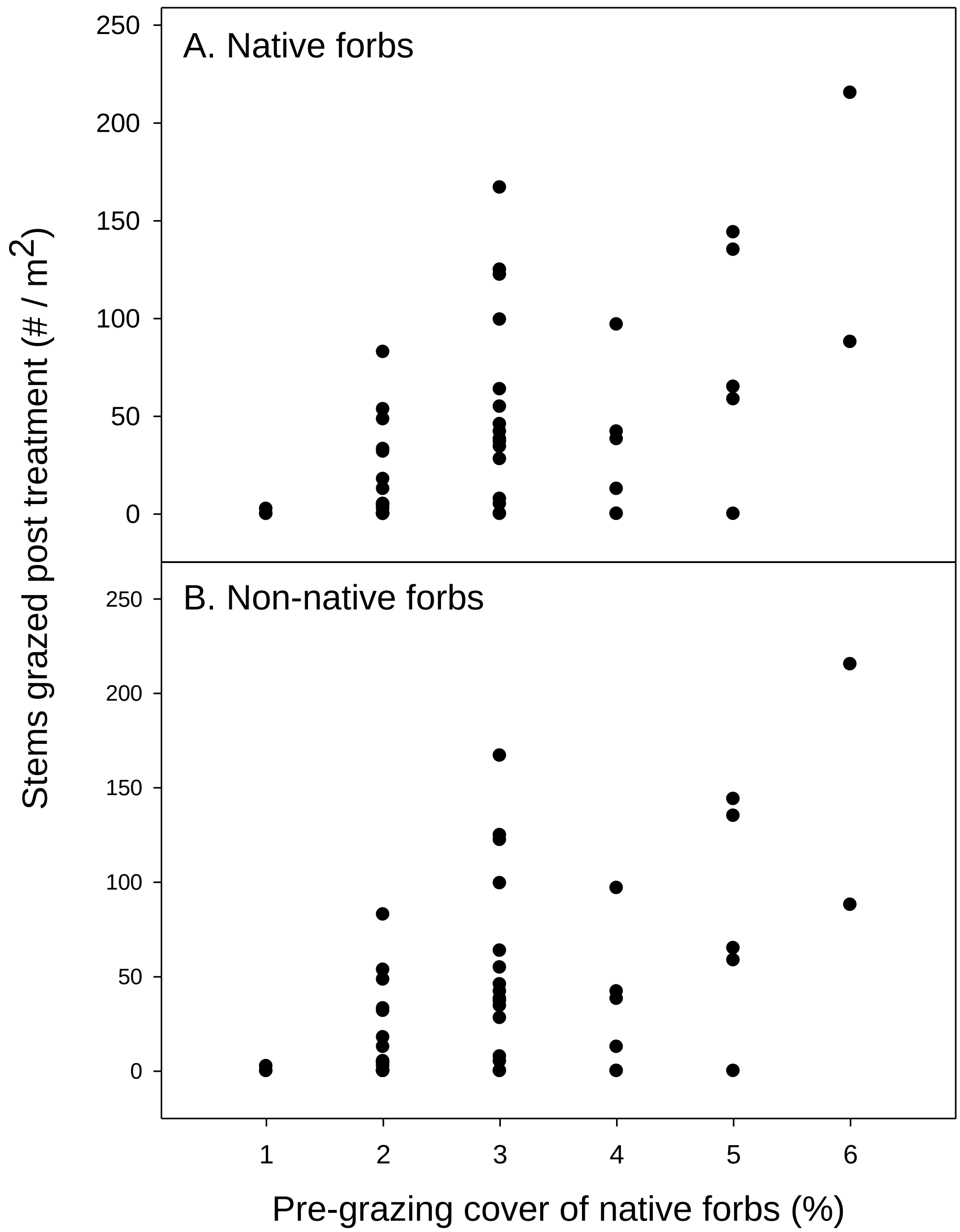

A. Native forbs
B. Non-native forbs
Stems grazed post treatment (# / m^2)
Pre-grazing cover of native forbs (%)
250
200
150
100
50
0
1
2
3
4
5
6

Fig. 5

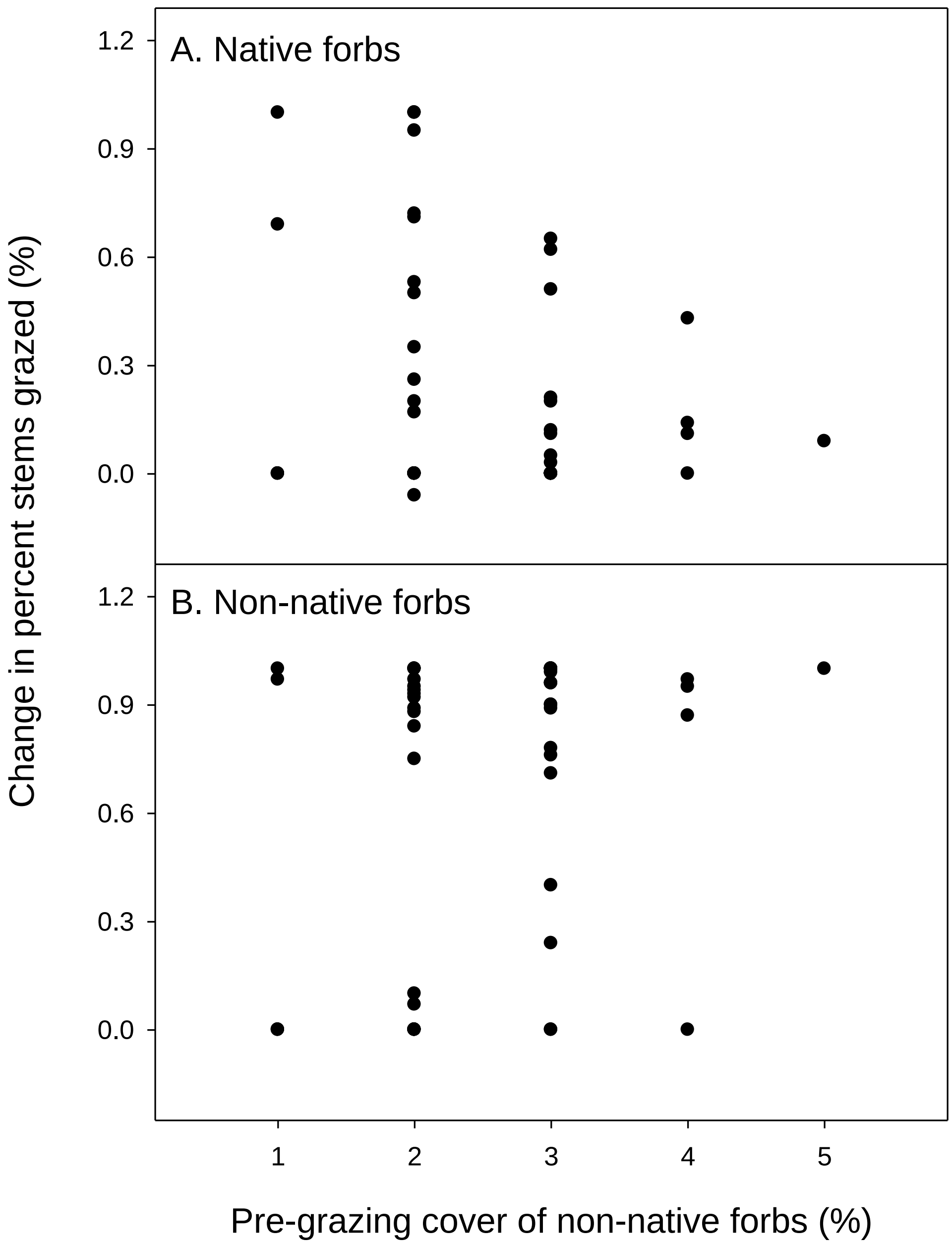
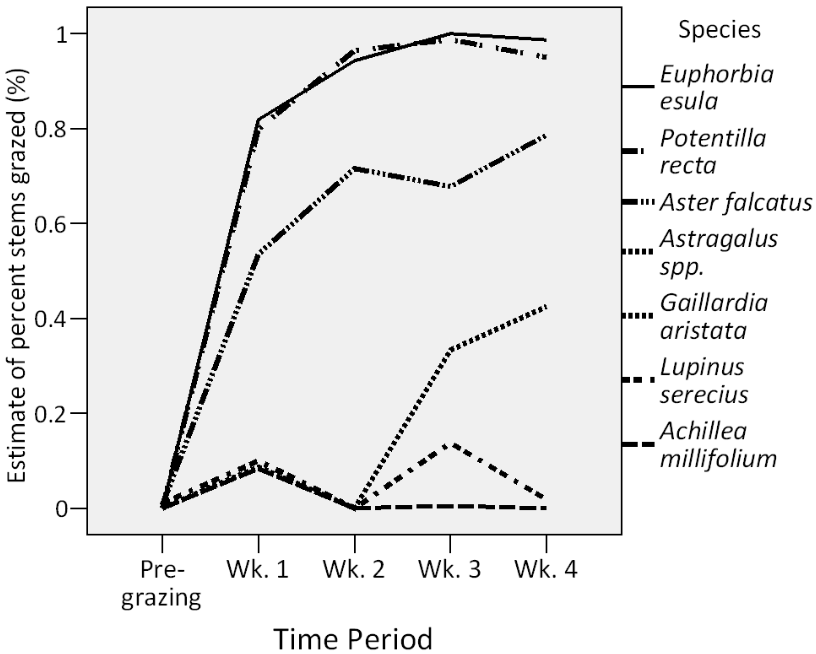

A. Native forbs
B. Non-native forbs
Change in percent stems grazed (%)
Pre-grazing cover of non-native forbs (%)
1.2
0.9
0.6
0.3
0.0
1
2
3
4
5

Fig. 6


Species
Euphorbia esula
Potentilla recta
Aster falcatus
Astragalus spp.
Gaillardia aristata
Lupinus serecius
Achillea millifolium
Estimate of percent stems grazed (%)
1
0.8
0.6
0.4
0.2
0
Pre-grazing
Wk. 1
Wk. 2
Wk. 3
Wk. 4
Time Period

Appendix 1: *Seedling Establishment in Feces of Domestic Sheep Used for Weed Control*

Introduction

One increasingly popular method to control invasive weeds is the use of domestic sheep grazing, which can be effective as part of an integrated, long-term management strategy (Landgraff et al. 1984; Olson and Wallander 1998; Bangsund et al. 2001). Little is known; however, about the impacts of this practice on dispersal of target invasive weeds via feces of sheep grazing weed infested areas. Dispersal by feces is only possible for those species that remain viable after ingestion. Although it is known from controlled feeding trials that some weeds, such as *E. esula* (Olson et al. 1997; Olson and Wallander 2002), can germinate after ingestion, information on which weedy plants may germinate in "natural" conditions (from intact sheep fecal samples) is not known. Controlled feeding trials and viability tests on ingested seed have been done for *E. esula* and *C. maculosa*; (Olson et al. 1997; Olson and Wallander 2002). However, no studies have investigated which invasive plants germinate from fecal samples collected from free-ranging animals. In addition, little is known about which native plant species may germinate from intact sheep fecal samples. Fecal dispersal of native or non-native plant seeds is a non-target effect of grazing management programs that could impact vegetation restoration where sheep grazing is utilized as a management option.

As a side project to my primary thesis work, I assessed germination rates of forb and graminoid seeds in feces collected from sheep used for weed control in intermountain grasslands. This investigation was done in collaboration with Missoula Parks and Recreation (Missoula, Montana), which manages approximately 1,500 ha of public lands. The specific research questions that I addressed are:

1) Do forb and graminoid seeds germinate after passing through sheep and being excreted in feces?

2) If so, do germination rates differ from fecal samples deposited at different times throughout the summer?

Methods

I assessed the number of forb and graminoid seedlings that germinated from sheep feces by planting fecal samples in soil and measuring rates of seedling germination in a controlled greenhouse environment. The fecal samples were collected from free-grazing sheep used to control *E. esula* on Mount Jumbo at Waterworks Hill located at the southern end of the Rattlesnake Mountains in Northwest Montana. Predominant slopes in the study area range from ca. 35-45%, and soils range from gravelly loams to sandy silts (Natural Resources Conservation Service 2009). Elevation in the study area ranges from 1150-1250 m, and average annual precipitation is approximately 35 cm, although Mount Jumbo received nearly 41 cm of precipitation during the study time period (National Oceanic and Atmospheric Administration 2009). Embedded within E. esula infested areas are patches of remnant plant communities in which natives dominate but non-native forbs still account for a substantial component of total herbaceous plant cover. The dominant native plants are bunchgrasses, including *Agropyron spicatum* (bluebunch wheatgrass), *Poa secunda* (Sandberg bluegrass), *Koeleria macrantha* (Junegrass), and *Festuca idahoensis* (Idaho fescue).

In 2009, fecal samples were collected once a week for thirteen weeks during June (time periods 1-4), July (time periods 5-7), August (time periods 8-12) and September (time period 13). At each collection date, samples were collected from six randomly selected sheep grazing in the study area (n=78; 6 sheep/week x 13 weeks). The last set of fecal samples was collected four days after sheep were moved from the North Hills to the ranch where they overwinter.

All fecal samples were oven dried at ca. 19^{0} C for ca. 48 hr. In October 2009, I weighed and placed each of the 78 samples directly on top of soil in 350-g containers that were sterilized with a mild bleach solution and filled with Sunshine Mix #2 weed-free potting soil. Samples were chopped or coarsely broken to simulate hoof action. I also filled 13 additional control pots with Sunshine Mix #2 potting soil in order to determine rates of germinating from the soil alone.

All containers were kept in a greenhouse and watered three-to-four times per week during October and November 2009 and from mid-March to July 2010. Plants were not watered from December 2009 to early March 2010, to simulate winter dormancy. Seedlings were tracked individually, and pots were monitored bi-weekly to determine newly germinating seedlings. Number of germinates per pot were recorded by growth form (graminoid and forb), and surviving seedlings were identified by species (whenever possible) and harvested on July 23, 2010. Species nomenclature follows Lackschewitz (1991) for forbs and Lavin and Seibert (2011) for graminoids.

Prior to statistical analyses, I calculated total number of germinates (forbs and graminoids) in each of the 13 time periods (n=6 replicate fecal samples at each time period) and in control pots (n= 13). To assess differences in germination among fecal collection periods (and between fecal samples and control pots (with no fecal samples), I used Kruskal Wallis tests (Ott and Longnecker 2010) with separate tests for forbs and grasses. Statistical analyses was done using SPSS 15.0 (SPSS, 2009), with an alpha level of 0.05 as the criterion for statistical significance.

Results

A total of 80 forb seedlings (mean of two/pot) germinated from fecal samples. In comparison, only four forb seedlings (<one/pot) germinated in control pots. One forb, *Medicago lupulina,* germinated in both the control pots and in fecal samples; this species was excluded from analysis. *Achillea millefolium* also germinated in control pots but did not occur in any pots with fecal samples. Many of the forbs which germinated in the study plots were difficult to identify: 53% of

forbs died at the cotyledon stage. A total of five species of forbs (40% of the total germinants) had germinants that survived beyond the cotyledon stage and were identifiable (Table A1); an additional 5% of forbs that survived beyond the cotyledon stage were not identifiable. Number of forb germinates varied significantly among time periods (h = 24.094, p = 0.020, df = 5); however, germination rates only differed significantly between week thirteen and all earlier time periods (Fig. A1, A).

A total of 45 graminoid seedlings (mean of two/pot) germinated from fecal samples. In comparison, no graminoids germinated in the control pots. Many of the grasses which germinated in the study pots were difficult to identify: 33% of germinants died at the cotyledon stage. Only two species of grasses (36% of the total germinants) had germinants that survived beyond the cotyledon stage and were identified (Table A1); 31% of graminoids that survived beyond the cotyledon stage were not identifiable. Graminoid seedling germination varied significantly among time periods (h= 31.967, p = 0.002, df =5). As with the forbs, the only significant difference was between pots grown with fecal samples from week thirteen and those grown with samples from the other collection periods (Fig. A1, B).

Discussion and Recommendations

Surviving species in experimental fecal samples were primarily weedy or invasive, indicating that sheep grazing *E. esula* may be facilitating the spread of non-native species including *Sisymbrium* spp., *Bromus* spp. *and P. compressa* by dispersing seed in their feces. Although sheep fecal dispersal seemed to favor non-native plants, 2 native forbs germinated from the fecal samples, indicating that sheep may also be facilitating the spread of native forb seeds.

Although statistically significant differences in mean seedling germination between time periods are reported, it is important to consider that germination in pots with fecal samples was very low (<5) for both forbs and graminoids regardless of collection period. With this caveat, I found that more forbs germinated from sheep fecal samples that were collected later in the summer, while graminoid establishment rates were higher in samples collected earlier in the summer (mid-June and July-early August) indicating that timing of a grazing program is important when considering non-target impacts due to fecal dispersal.

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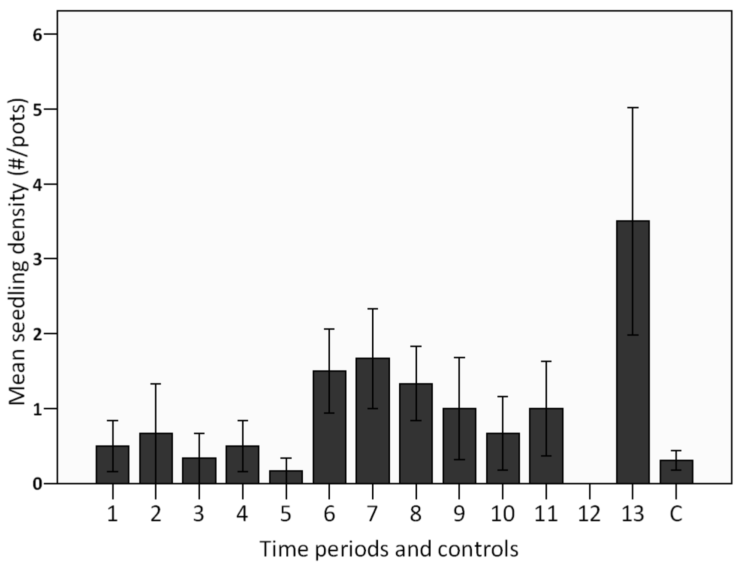
Table A1 Scientific and common names and origin (native vs non-native invasive) of species harvested from sheep fecal samples.

Scientific Name	Common name	Status
FORBS		
Draba nemorosa	Draba	Native
Plantago patagonica	Common plantain	Native
Chenopodium album	Lambsquarters	Non-native
Potentilla recta	Sulfur cinquefoil	Non-native
Sisymbrium sp.	Tumble mustard	Non-native
GRAMINOIDS		
Bromus spp.	Cheatgrass/Japanese brome	Non-native
Poa compressa	Canada bluegrass	Non-native

Fig. A1. Mean (+/- 1 standard error) density of forbs (A) and graminoids (B) that germinated from fecal samples collected at thirteen different time periods and in control pots (C).

A.



B.