



## Evidence-Targeted Grazing Benefits to Invaded Rangelands Can Increase over Extended Time Frames



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### ABSTRACT

Targeted grazing uses livestock to address woody plant encroachment, flammable biomass accumulations, exotic weed invasions, and other management issues. In principle, a feature distinguishing targeted grazing from production-orientated grazing is stocking regimes (i.e., rates, timings, and durations) are chosen to encourage heavy defoliation of unwanted plants at sensitive growth stages. In practice, there are limited data available to guide stocking regime choices. Those data that do exist derive mostly from short-term studies, so the long-term effects of targeted grazing most concerning to managers remain highly uncertain. In a previous study, we imposed clipping treatments to identify defoliation levels and timings effective against the invader leafy spurge (*Euphorbia esula* L.). Most treatments simulated defoliation by sheep, the animal most commonly used for leafy spurge grazing, though a baseline treatment simulated defoliation by cattle, an animal tending to avoid leafy spurge. The two most effective treatments, which gave similar responses through the end of the previous study, defoliated leafy spurge and other species either before or during leafy spurge flowering. One goal of the current study was to determine if these responses remained similar or diverged over 5 additional treatment years. The other goal was to determine if differences between simulated sheep and cattle grazing treatments increased over time. In the current study, it became increasingly clear that defoliation before flowering was most damaging to leafy spurge, even though defoliation during flowering removed greater leafy spurge biomass. Compared with simulated cattle grazing, simulated sheep grazing before flowering reduced leafy spurge biomass production 74% (52%, 86%) [mean (95% confidence interval)] and increased resident species (mostly grasses) biomass production 40% (14%, 74%) by study's end. Leafy spurge biomass differences between treatments increased gradually over the study period, suggesting long-term research is needed to accurately compare targeted grazing treatments.

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### Introduction

Targeted grazing manages livestock to encourage favorable shifts in plant communities. An advantage of targeted grazing over other rangeland management tools (e.g., herbicides, fire) is that commodities (e.g., meat, fiber) are produced in the process of improving range condition. Targeted grazing by cattle, sheep, goats, and other species has been tested and/or used to manage invasive weeds (De Bruijn and Bork, 2006; Goehring et al., 2010; Henderson et al., 2012), potentially toxic native plants (Goodman et al., 2014), woody plant encroachment (Utsumi et al., 2010), and high accumulations of flammable biomass (Diamond et al., 2009; Lovreglio et al., 2014).

A feature distinguishing targeted grazing from production-orientated grazing is that livestock species are chosen on the basis of their strong dietary preferences for unwanted plants. Another distinguishing feature is that stocking regimes (i.e., rates, timings, and durations) are chosen to encourage intense, selective grazing of unwanted plants when they are particularly sensitive to defoliation (Launchbaugh and Walker, 2006). Unfortunately, because targeted grazing data are limited, stocking regime choices often reflect more art than science. With certain invasive weeds, data from small numbers of targeted grazing studies are available to aid stocking decisions, but the studies have usually run only 2 or 3 years (Diamond et al., 2012; Olson and Wallander, 1998), with 4- to 5-year studies being fairly rare (Jacobs et al., 2006; Johnston and Peake, 1960; Kirby et al., 1997; Lacey and Sheley, 1996; Lym et al., 1997; Sheley et al., 2004) and only one study running >5 years (Lodge et al., 2005). Because study durations have been so short, little is known about the long-term effects of targeted grazing that most concern managers. Targeted grazing is inherently a long-term management strategy because of high implementation costs (e.g., purchasing appropriate livestock species,

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adapting fencing and other facilities, employing herders) (Macon, 2014) and because invader populations quickly rebounding if targeted grazing or other forms of management (i.e., herbicides, prescribed fire) are discontinued (DiTomaso et al., 2006; Lym et al., 1997; Young et al., 1998). Plant community dynamics observed over the course of short-term studies suggest these studies underestimate long-term benefits of targeted grazing. In particular, short-term studies often observe plant community compositions gradually shifting from invaders toward more desirable species over 2- to 3-year periods (De Bruijn and Bork, 2006; Frost and Mosley, 2012; Rinella and Hileman, 2009), and these gradual shifts suggest targeted grazing benefits would magnify if studies ran longer.

Rinella and Hileman (2009) used simulated grazing (i.e., clipping) to study defoliation effects on plant communities invaded by leafy spurge (*Euphorbia esula* L.), an exotic forb dominating ~1.5 million ha of US rangelands (Duncan et al., 2004). This paper reports on continuing Rinella and Hileman's (2009) two most promising simulated targeted grazing treatments 5 additional years beyond their original 3-year study. The two treatments simulated defoliation by sheep grazing alone or mixed with cattle (~50% of resident species biomass defoliated, leafy spurge defoliated to mimic sheep grazing). The factor differentiating the two treatments was defoliation timing: Defoliation occurred at leafy spurge preflowering or flowering stages. Responses to these treatments were statistically indistinguishable through the end of the previous study (Rinella and Hileman, 2009), and the goal in continuing these treatments was to determine if one or the other treatment emerged as superior over longer time frames. In addition to the two targeted grazing treatments, we also continued a third baseline treatment designed to simulate effects of cattle grazing alone (~50% of resident species biomass defoliated, leafy spurge not defoliated). Continuing this treatment allowed us to meet another goal, which was to determine if biomass differences between the baseline cattle grazing treatment and the targeted grazing treatments increased over longer periods. If targeted grazing continues reducing leafy spurge populations and/or increasing desired species populations beyond the first 3 years, this would suggest short-term studies have potential to underestimate long-term benefits of targeted grazing.

## Methods

### Site Descriptions

Our three southeast Montana study sites were historically grazed by cattle but were fenced for the study to exclude livestock. Sites were separated by 64–106 km, and Sites 1, 2, and 3 were a loamy range site of the Havre-Harlake complex, a Glendive loam range site, and a silty loam site of the Glendive-Havre complex, respectively. Site 1 (46°16'38"N, 105°08'56"W) pretreatment leafy spurge stem densities were 50–100 m<sup>-2</sup>; grasses were western wheatgrass (*Pascopyrum smithii* [Rydb.] Á. Löve), Kentucky bluegrass (*Poa pratensis* L.), and blue grama (*Bouteloua gracilis* [Willd. ex Kunth] Lag. ex Griffiths); and forbs included dandelion (*Taraxacum officinale* [L.] Weber ex F.H. Wigg.) and salsify (*Tragopogon dubius* Scop.). Site 2 (46°41'49"N, 104°39'48"W) pretreatment leafy spurge stem densities were 10–20 m<sup>-2</sup>, smooth brome (*Bromus inermis* Leyss.) was the only grass, and forbs included yellow sweetclover (*Melilotus officinalis* [L.] Lam.) and salsify. Site 3 (46°20'50"N, 105°59'11"W) pretreatment leafy spurge stem densities were 150–300 m<sup>-2</sup>; grasses were Japanese brome (*Bromus arvensis* L.), downy brome (*Bromus tectorum* L.), and western wheatgrass; and forbs included salsify and dandelion.

### Experimental Design

Three twice-replicated treatments were arranged in a randomized complete block design (3 sites × 3 treatments × 2 replications = 18 plots). Treatments were 1) leafy spurge and resident species defoliated before leafy spurge flowering (April 23–May 21) when stems were

25 ± 5 cm tall (mean ± SD), 2) leafy spurge and resident species defoliated during leafy spurge flowering (May 27–June 27) when stems were 60 ± 10 cm tall, and 3) only resident species defoliated during leafy spurge flowering. In all treatments, resident species were defoliated at a height selected to remove ~50% of biomass, with this height determined by clipping and weighing samples adjacent to study sites. Leafy spurge defoliation levels mimicked observations made on sheep grazing leafy spurge (Rinella and Hileman, 2009). Accordingly, stems were clipped to ground level in the preflowering treatment, and stems were clipped to remove 25% (by height) in the flowering treatment. Plots were 1.0 × 1.0 m, and to obviate edge effects, we extended leafy spurge defoliations across a ~10 m buffer surrounding plots using an electric string trimmer. Treatments were applied 2005–2012 at Sites 1 and 2 and 2006–2012 at Site 3.

### Data Collection

Our goal was to estimate annual leafy spurge and resident species biomass production (biomass removed by clipping plus biomass remaining in plots). Accordingly, removed biomass was collected, dried (48 h, 60°C), and weighed. Leafy spurge biomass remaining was estimated by applying calibrated regressions of biomass on stem heights to stems measured at peak standing crop (late July to early August). Calibration data came from 100 stems gathered outside plots at each site. Defoliating half the stems allowed us to develop separate regressions for defoliated and not-defoliated stems (Rinella and Hileman, 2009). Resident biomass remaining was estimated by drying and weighing biomass clipped to ground level from two frames (300 cm<sup>-2</sup> in 2005, 800 cm<sup>-2</sup> other years) at peak standing crop. These frames were randomly placed conditional on avoiding areas clipped the previous year. The one exception was 2007, when remaining leafy spurge and resident species biomass was estimated by clipping entire plots in August after plants senesced (Rinella and Hileman, 2009).

### Data Analysis

Our bivariate response was leafy spurge and resident plant biomass produced per plot per year. We assumed a bivariate normal distribution for the data,

$$\log y_i \sim N(\mathbf{B}\mathbf{X} + \boldsymbol{\alpha}_{p(i)} + \boldsymbol{\gamma}_{b(i)} + \boldsymbol{\delta}_{t(i)} + \boldsymbol{\varphi}_{m(i)} \boldsymbol{\Sigma}), \quad (1)$$

where  $\mathbf{y}_i$  is the (2 × 1) response vector for observation  $i$ . The (2 ×  $p$ ) matrix  $\mathbf{B}$  contains regression coefficients, and  $\mathbf{X}$  is a ( $p$  × 1) vector of predictors. Rows of  $\mathbf{X}$  allowed for modeling intercepts, site and treatment effects, year covariates, year × treatment interaction covariates, and pretreatment leafy spurge and resident species biomass covariates (for details on pretreatment sampling, see Rinella and Hileman, 2009). March 1–June 30 precipitation was another covariate: This is when most precipitation and ~90% of plant growth occurs at our sites (Vermeire et al., 2009). Posterior predictive checking, a diagnostic approach that compares real data with data simulated from the fitted model, indicated site × treatment and precipitation × treatment effects were not needed for the model to fit the data (Gelman et al., 2014). This approach also justified setting certain elements of  $\mathbf{B}$  to zero. These elements corresponded to the year × treatment covariate for the resident species response, the effect of pretreatment leafy spurge biomass on resident species biomass, and the effect of pretreatment resident species biomass on leafy spurge biomass. The vectors  $\boldsymbol{\alpha}$ ,  $\boldsymbol{\gamma}$ ,  $\boldsymbol{\delta}$ , and  $\boldsymbol{\varphi}$  are plot, block, year, and year × site interaction effects, respectively; functions  $p$ ,  $b$ ,  $t$ , and  $m$  map vector elements to observations; and  $\boldsymbol{\Sigma}$  is a covariance matrix. Elements of  $\mathbf{B}$  were assigned uniform Bayesian prior distributions with support on the whole real line, and the  $\boldsymbol{\alpha}$ ,  $\boldsymbol{\gamma}$ ,  $\boldsymbol{\delta}$ , and  $\boldsymbol{\varphi}$  were assigned bivariate normal distributions with mean  $\mathbf{0}$ , variance matrix  $\boldsymbol{\Lambda}$ . Inverse-Wishart distributions with 2 degrees of freedom and identity matrix as the scale were assigned to each  $\boldsymbol{\Lambda}$  and

to  $\Sigma$  (Gelman et al., 2014). A Gibbs sampling algorithm implemented in FORTRAN was used to fit the model (Gelman et al., 2014; Intel Corporation, 2013). We based inferences on 95% confidence intervals, and probabilities effects were different (Pr).

**Results**

Defoliating leafy spurge before flowering reduced its biomass production compared to the baseline simulated cattle grazing treatment (Fig. 1). The magnitude of the difference between these two treatments increased over time. For example, compared with the baseline treatment, defoliating leafy spurge preflowering decreased its biomass 26% (6%, 41%) in year 3 and 74% (52%, 86%) in year 8.

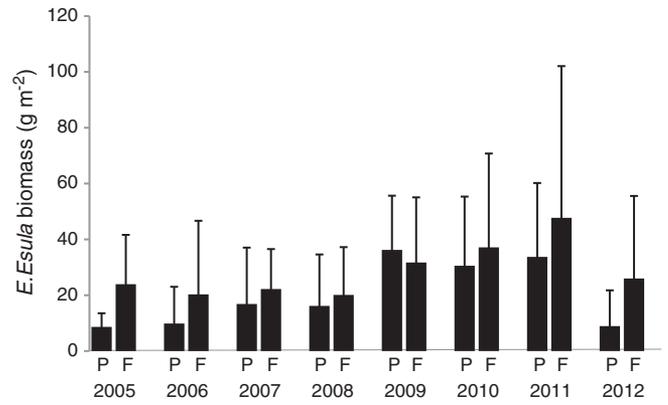
Defoliating leafy spurge during flowering likely reduced its biomass production compared to the baseline treatment (see Fig. 1). Flowering stage defoliation proved less damaging to leafy spurge than the preflowering defoliation, particularly in later years of the study (see Fig. 1). This was so even though defoliation during flowering tended to remove greater leafy spurge biomass than defoliation before flowering (Fig. 2).

Compared with the simulated cattle grazing treatment, treatments defoliating leafy spurge at preflowering and flowering stages resulted in 40% (14%, 74%) and 26% (– 5%, 66%) greater resident species biomass, respectively. The two leafy spurge defoliation treatments did not differ significantly in terms of resident species biomass production (Pr = 0.30). Compared with flowering stage defoliation, preflowering defoliation removed less resident species biomass (Fig. 3), which is unsurprising given there was naturally less biomass earlier in the growing season.

**Discussion**

Our study suggests targeted grazing benefits can continue accruing over extended periods (see Fig. 1), suggesting short-term studies run a risk of underestimating the value of targeted grazing strategies. Short-term studies can provide useful information regarding livestock dietary preferences for invasive weeds (Henderson et al., 2012; Kleppel and LaBarge, 2011) and initial plant community responses (Diamond et al., 2012; Wallace et al., 2008), but long-term research is needed to quantify the long-term effects of targeted grazing most relevant to managers (Macon, 2014).

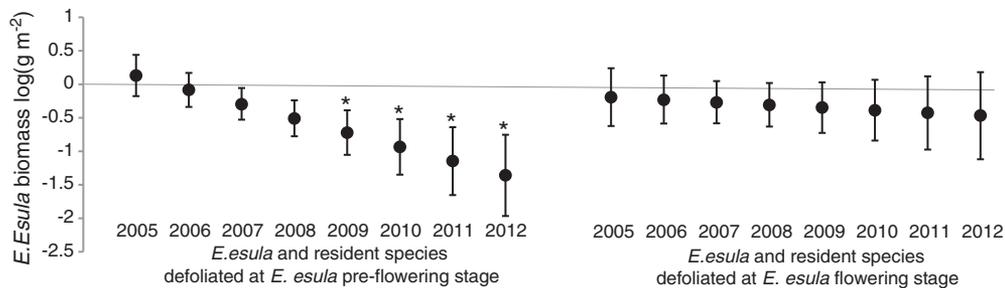
Leafy spurge produced less biomass in response to preflowering than flowering stage defoliations (see Fig. 1). This finding is in general agreement with collective results of seven sheep and goat grazing studies. Three of the studies had stocking periods appreciably overlapping the preflowering stage, and these studies found grazing reduced leafy spurge abundances (Jacobs et al., 2006; Johnson and Peake, 1960; Lym et al., 1997). The other four studies stocked during later stages and observed no effect (Lacey and Sheley, 1996; Olson and Wallander, 1998; Seefeldt et al., 2007). Conversely, the finding that preflowering defoliation is most damaging to leafy spurge contrasts with Kirby et al. (1997), who found flowering stage defoliation was most damaging. A factor



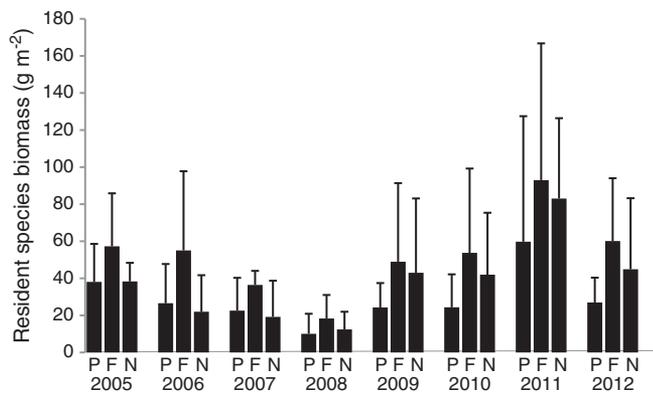
**Fig. 2.** Leafy spurge biomass removed. Leafy spurge biomass (mean + SD) removed by clipping at preflowering (P) and flowering (F) stages.

serving to moderate confidence in the Kirby et al. (1997) finding, however, is that the small portions of plots they measured in a given year were excluded from defoliation that year, so their preflowering defoliation data reflect an artificial 1.5-growing season rest period before measurement. Additionally, the Kirby et al. (1997) preflowering defoliation was artificially light compared with observations on leafy spurge grazed by sheep (Rinella and Hileman, 2009). Allocation of resources to herbivore defense may explain why leafy spurge is most sensitive to defoliation before flowering (Gershenson, 1994; Stamp, 2003). Defoliation stimulates leafy spurge to redirect resources from production of biomass to production of tannins and perhaps other carbon-based feeding deterrents (Roberts and Olson, 1999). If leafy spurge elevates tannin production the remainder of the growing season following defoliation, it redirects resources from biomass production to defense for a longer period of time following preflowering than flowering stage defoliation. Another possibility is leafy spurge defoliated before flowering experienced elevated competition for light. Grasses had a substantial height advantage over leafy spurge for a time following pre-flowering defoliation, while leafy spurge remained taller than grasses following flowering stage defoliation.

Effective targeted grazing strategies requiring relatively few animals are desirable because of the high cost of acquiring and managing large numbers of a new livestock species. Of treatments evaluated here or by Rinella and Hileman (2009), the treatment most effective against leafy spurge (i.e., preflowering treatment) removed the least leafy spurge biomass and would thus likely require the fewest animals. Moreover, the declining leafy spurge trend of the preflowering treatment suggests, over time, this treatment’s defoliation levels could be maintained with decreasingly lower stocking rates and/or shorter stocking durations. For this to be the case, animals would need to increase leafy spurge foraging effort as its availability declined. Some studies have shown sheep and goats consuming leafy spurge at high rates relative to its availability (Kronberg and Walker, 1999; Walker et al., 1994),



**Fig. 1.** Effect of simulated grazing on leafy spurge and resident species biomass. Point estimates (dots) and 95% confidence interval (bars) estimating effects of treatments that defoliated leafy spurge and resident species to mimic sheep grazing. Negative values indicate treatments lowered leafy spurge biomass compared with a baseline treatment (zero line) that defoliated only resident species to mimic cattle grazing. Asterisks denote significant differences (Pr > 0.95) between preflowering and flowering stage treatments within years.



**Fig. 3.** Resident species biomass removed. Resident species biomass (mean + SD) removed from plots. Treatments were clipping of leafy spurge and resident species at the leafy spurge preflowering stage (P), clipping of leafy spurge and resident species at the leafy spurge flowering stage (F), and clipping of only resident species at the leafy spurge flowering stage (N).

suggesting these species may commonly increase leafy spurge foraging effort in response to declining availability. Treatments discontinued after our third study year illustrate the general importance of stocking animals with high selectivity for the target species (Rinella and Hileman, 2009). Depending on the specific treatment and year, the discontinued treatments, which clipped resident species closer to ground level, removed 5%–29% greater resident species biomass than treatments of the current paper. In some cases, two treatments identical except for this clipping height difference had opposite effects: High clipping height treatments boosted resident species at the expense of leafy spurge while low clipping treatments boosted leafy spurge at the expense of resident species. Grazing selectivity appears to be a critical factor regulating invaded rangeland responses to targeted grazing.

## Implications

Together with Rinella and Hileman (2009), our study suggests targeted grazing strategies composed of appropriate defoliation timings can consistently improve plant species compositions on leafy spurge-invaded rangelands. Our most effective timing reduced invader biomass 74% (52%, 86%) and increased resident species (predominantly forage grasses) biomass 40% (14%, 74%) in the eighth and final year of our study. Other timings and intensities had either considerably smaller positive effects or increased the invader and reduced resident species (Rinella and Hileman, 2009; see Fig. 1 of the current paper). These results illustrate effective targeted grazing entails more than stocking animals that consume invasive weeds. Animals must be stocked at appropriate times and rates to encourage intense, somewhat selective defoliation of weeds at vulnerable growth stages. Finally, our data suggest positive effects of targeted grazing may be slow to emerge and may increase over extended time frames. From a management perspective, this implies patience and careful monitoring may be needed to determine if targeted grazing is working. From a research perspective, this implies longer studies are needed to accurately estimate long-term benefits of targeted grazing strategies.

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