



## 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

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