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Research Note

Response of Biomass and Seedbanks of Rangeland Functional Groups to Mechanical Control of Yellow Starthistle

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Abstract

Yellow starthistle (*Centaurea solstitialis* L.) is a nonnative pest of rangelands that decreases forage quality and yield. Mowing may control starthistle effectively and complement herbicide use in an integrated pest management strategy, but little research has investigated its effects on nontarget vegetation. We monitored biomass and seedbank size of annual and perennial species, in addition to starthistle, in response to 3 yr of mowing treatments, either mowing alone or in combination with solarization tarps or thatch removal. All mowing treatments were very effective at reducing starthistle biomass and seedbank: mowing alone reduced biomass $92 \pm 2\%$, mowing with thatch removal $91 \pm 1\%$, and mowing with solarization $95 \pm 1\%$. Compared to seedbank sizes in the control plots, yellow starthistle seedbank decreased by 100% (mowing alone), 92% (mowing + thatch removal), and 100% (mowing with solarization) after 3 yr of treatment. Mowing also significantly improved perennial species' biomass. Annual species' biomass varied on a year-to-year basis but was not significantly affected by any treatment. Seedbank sizes of annuals and perennials also did not differ according to mowing treatment. This research indicates that late-season mowing can effectively reduce starthistle biomass without adverse effects on other vegetation and that mowing alone is sufficient to reduce starthistle seedbank size without additional methods of decreasing seed rain.

Resumen

El cardo amarillo (*Centaurea solstitialis* L.) es una plaga no nativa de los pastizales que disminuye la calidad y rendimiento del forraje. Por medio del corte se puede tener un control efectivo del cardo amarillo y complementarlo con el uso de herbicida como estrategia de manejo integrado de plagas, pero poca investigación se ha hecho para conocer los efectos en la vegetación no seleccionada. Monitoreamos la biomasa y el banco de semillas de especies anuales y perennes además de el cardo amarillo, en respuesta a tres años de tratamientos de cortes ya sea cortado solo el cardo amarillo ó en combinación con lonas de solarización o techos removibles. Todos los tratamientos de corte fueron muy efectivos en reducir la biomasa y banco de semilla del cardo amarillo: el corte por si solo redujo la biomasa en $92 \pm 2\%$, el corte con techo removible $91 \pm 1\%$ y corte con solarización $95 \pm 1\%$.Comparado con el tamaño de los bancos de semillas en las parcelas de control, el banco de semilla del cardo amarillo se redujo en un 100% (solo corte), 92% (corte + techo removible) y 100% (corte con solarización) después de tres años de tratamiento. El corte también mejoro significativamente la biomasa de especies perennes. La biomasa de especies anuales varió año con año pero no afectoda significativamente por ninguno de los tratamientos. Los tamaños de los bancos de semillas de anuales y perennes tampoco tuvieron diferencias de acuerdo al tratamiento de corte. Esta investigación indica que el corte al final de la temporada puede efectivamente reducir la biomasa del cardo amarillo sin tener efectos adversos en la otra vegetación y que el corte por sí solo es suficiente para reducir el tamaño del banco de semillas sin métodos adicionales que reduzcan la semilla de lluvia.

Key Words: integrative pest management, invasive species, Mediterranean grassland, nontarget effects, phenology, weed

INTRODUCTION

The European annual *Centaurea solstitialis* (Asteraceae), or yellow starthistle, has become a widespread pest of rangelands in California since its introduction in the 19th century. Ruminants can eat the plant in its early stages of growth, but it causes a fatal neurological disease in horses and after bolting harbors spines that prevent other livestock from grazing. Loss of forage due to yellow starthistle costs California cattle ranchers US$7.65 million per year in addition to the US$9.45 million per year they spend on controlling the invasion's spread (Eagle et al. 2007). The late-flowering, deeply rooted species also draws down soil moisture in late summer, when most other annuals have senesced, causing water losses that may amount to as much as US$75 million in the Sacramento River watershed alone (Gerlach 2004).

Long-distance spread of yellow starthistle occurs mainly through human activities like road building and haying, while wind and animal vectors disperse the seeds short to medium distances. Roché (1992) determined that 92% of achenes travel < 1 m from the parent plant. The seeds are not long lived in the soil, with the vast majority germinating in the first year and the seedbank 97–99% depleted by the third year (Joley et al. 1992; Benefield et al. 2001). Consequently, most strategies for yellow starthistle control have focused on reducing seed production or reducing plant density prior to seed set.

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Several methods have been determined to be effective at reducing seed set or starthistle density, but none is free of drawbacks, including negative effects on other vegetation. Controlled burns are effective at reducing starthistle biomass and potentially other nonnative weeds (DiTomaso et al. 1999a) but pose logistical limitations for ranchers because of summer air quality regulations and the potential liability for wildfire escape. Six biological control agents, all seed predators, are established in California and have been shown to reduce starthistle seed production by as much as 75% (Pitcairn and DiTomaso 2000). However, several researchers have concluded that biocontrol is inadequate to control starthistle spread on its own and should be coupled with other methods of reducing starthistle density (Gutierrez et al. 2005; Garren and Strauss 2009). The herbicide clopyralid is the method of starthistle control rated most effective by California cattle ranchers, though it kills leguminous forage species like clover (Aslan et al. 2009). Additionally, clopyralid use has been shown to reduce the abundance and fecundity of certain native species in California grasslands (Morghan et al. 2003), and herbicide resistance may develop as its use increases. Repeated use of picloram in Washington resulted in a picloram-resistant population of yellow starthistle that also showed resistance to clopyralid, which has a similar mode of action (Fuerst et al. 1996).

Clipping methods, such as mowing and grazing, are useful if yellow starthistle phenology is taken into consideration. If mowed or grazed early in the season, compensatory growth responses produce more numerous buds or seedheads (Thomsen et al. 1997; Wallace et al. 2008) and may intensify yellow starthistle's effects on native plants (Callaway et al. 2006). By contrast, late-season mowing can reduce yellow starthistle densities and seed production (Benefield et al. 1999) for plants with the erect branching pattern typical of invasions in pastures.

Late-season mowing may therefore have a role in an integrated pest management strategy combined with herbicides, occasional burns, or biological control (DiTomaso et al. 2000), but the effects of this technique on nontarget species have not been well studied. Native perennial grasses are alive and potentially flowering during the late summer when yellow starthistle mowing should occur. Annuals, though senesced at the time of mowing treatments, may be affected by the loss of residual thatch that shades plants during the spring growing season. One goal of this study was therefore to evaluate the effects of mowing treatments on the biomass and seedbank size of annual and perennial herbs.

The other goal of the study was to test whether additional measures taken after mowing could increase the speed of starthistle eradication. Because yellow starthistle achenes ripen early, the clipped biomass may contribute viable seed to the seedbank. We tested the effect of removing the biomass after mowing and covering it with a solarization tarp to kill seeds to determine if these measures provided additional reductions in starthistle biomass and/or seedbank size.

METHODS

Study Site Location

We chose study sites in the watershed of Ten Mile Creek near Laytonville (Mendocino County), California (lat 39°41′18″N, long 123°28′58″W). The watershed is characterized by steep slopes and soils (Shortyork-Yorkville-Witherell series) and has been exploited principally for cattle grazing, though our sites had not been grazed in over a decade. Mean annual precipitation is 100 cm, and mean annual temperature is 12°C. Starthistle invasion in this watershed progresses quickly along seasonal creek beds where we located our study sites in early August 2005. We identified 24 patches of invading *C. solsititalis* ranging in size from 9 m^2 to 30 m^2, all exhibiting 100% starthistle cover. Invaded patches were randomly assigned to one of four treatments (including control), and treatment was applied over the entire patch area. Plant biomass measurements and seedbank cores were taken in 0.25-m^2 subplots.

Treatments

The treatments were mowing alone (mow only), mowing followed by removal of mowed biomass (mow/remove), mowing followed by covering with a 4-mil black plastic tarp (mow/solarize), and a control. Plants were mowed using a handheld gas-powered hedge trimmer at a height of 5 cm, which was below the first branching point on the main stem of starthistle plants. Treatments were applied when $\sim$25% of plants had open flower buds and few or no individuals had completed flowering in August 2005, 2006, and 2007. We observed no regrowth of yellow starthistle plants after any mowing treatment in any year. Tarps were removed after 6 wk and before the first rains, except in 2007, when one rainstorm occurred before tarp removal.

Biomass Sampling

Beginning in the year after mowing treatments commenced, we harvested biomass by clipping all aboveground herbaceous vegetation to ground level within a 0.25-m^2 subplot in each invaded patch ($n = 6$ for each treatment type). Biomass harvests were performed in July and August 2006, 2007, and 2008; in 2006 and 2007, these harvests were completed before the next mowing treatments were applied. Annual plants had senesced by this time, but perennials were typically in flower. Each year, we randomly located subplots within the patch using a center stake as a reference point but deliberately excluded sampling locations within 0.25 m of the edge of the patch and any location that had experienced a biomass harvest in a previous year. Plant material was oven dried to constant weight at 55°C and sorted into three categories: annuals, perennials, and yellow starthistle. Annuals were mostly nonnative grasses; perennials were mostly native grasses, sedges, and rushes (Table 1). Previous years' biomass was readily distinguishable by its weathered appearance and was removed prior to weighing.

Seedbank Monitoring

After treatments were terminated, we collected soil cores in October 2008 to a depth of 2.5 cm with a 5.6-cm–diameter corer. Within each invaded patch, we randomly located four 0.25-m^2 subplots, and within each subplot, we took three soil cores and composited them. Composited cores from each subplot were crumbled into pots and germinated with twice-weekly waterings from December 2008 to February 2009,

Table 1. Most common annual and perennial species in yellow starthistle patches. Asterisk denotes nonnative species.

	Common name	Family
Annuals		
*Avena barbata**	Oat grass	Poaceae
*Briza minor**	Quaking grass	Poaceae
*Bromus diandrus**	Ripgut brome	Poaceae
*Bromus hordeaceus**	Soft chess	Poaceae
Poa annua	Annual bluegrass	Poaceae
*Erodium cicutarium**	Redstem filaree	Geraniaceae
*Medicago polymorpha**	Common burclover	Fabaceae
Plagiobothrys nothofulvus	Popcorn flower	Boraginaceae
Perennials		
Danthonia californica	California oatgrass	Poaceae
Dichanthelium acuminatum	Western panicgrass	Poaceae
Elymus multisetus	Squirreltail	Poaceae
*Holcus lanatus**	Common velvetgrass	Poaceae
Hordeum brachyantherum	Meadow barley	Poaceae
*Lolium perenne**	Perennial ryegrass	Poaceae
Carex nudata	Naked sedge	Cyperaceae
Cyperus eragrostris	Tall flatsedge	Juncaceae
Juncus patens	Common rush	Juncaceae
*Rumex crispus**	Curly dock	Polygonaceae
*Plantago lanceolata**	Narrowleaved plantain	Plantaginaceae
Vicia americana	American vetch	Fabaceae

coinciding with the peak of the rainy season. Germination occurred in an unheated greenhouse with ambient light. After 3 mo, seedling emergence appeared to stop, and all seedlings could be identified well enough to be classed as yellow starthistle, annual grasses and forbs, or perennials. Germination data from the four subplots were pooled for each starthistle patch, so $n = 6$ for each treatment type.

Data Analysis

We analyzed biomass harvests for starthistle, annual grasses and forbs, and perennials using two-way analysis of variance (ANOVA) with "year" and "treatment method" as fixed factors, coupled with the Holm–Sidak post hoc test for multiple comparisons. Data for perennials and starthistle were log transformed (using $\log[X+1]$) to correct heteroskedacity and account for zero values. Seedbank data were strongly nonnormal and skewed by zero values, so we used Kruskal–Wallis in place of a 1-way ANOVA. Where inadvertent destruction of two seedbank core samples unbalanced the study design, we used Dunn's post hoc test for pairwise comparisons. Significant results are $P < 0.05$.

RESULTS

Yellow starthistle biomass was affected by treatment method ($F = 21.989$; df = 3,71; $P < 0.001$) but not by year of observation (Fig. 1a). Analysis of pairwise comparisons determined that starthistle biomass decreased significantly in the mow-only ($t = 6.762$; $P < 0.0001$), mow/solarize ($t = 6.922$; $P < 0.0001$), and mow/remove ($t = 6.645$; $P < 0.0001$) treatments when compared to the control, but the mowing treatments did not differ from each other. Mowing treatments were effective at decreasing starthistle to zero or near-zero levels; no starthistle plants were observed in any of the mow-only treatment plots after the second year of treatment, and two-thirds of the mow/solarize and mow/remove treatment plots were also free of starthistle by the third year of treatment. The 3-yr average yellow starthistle biomass in control plots was $232.1 \pm 54.4\ g \cdot m^{-2}$ (Fig. 1d) but was decreased to $13.9 \pm 10.9\ g \cdot m^{-2}$ by mowing alone, $17.7 \pm 16.9\ g \cdot m^{-2}$ by mowing with removal, and $8.8 \pm 7.1\ g \cdot m^{-2}$ by mowing with solarization.

Biomass of annual grasses and forbs was not significantly affected by treatments (Fig. 1b) but did vary significantly between years ($F = 8.632$; df = 2,71; $P < 0.001$), with lower annual biomass in 2006 compared to 2007 ($t = 3.811$; $P < 0.001$) and 2008 ($t = 3.339$; $P < 0.01$) The 3-yr average biomass of annual grasses and forbs in control plots was $149.4 \pm 8.9\ g \cdot m^{-2}$ (Fig. 1d), $201.4 \pm 22.5\ g \cdot m^{-2}$ with mowing alone, $152.3 \pm 14.1\ g \cdot m^{-2}$ with mowing and removal, and $180.5 \pm 18.6\ g \cdot m^{-2}$ with solarizing. Treatment but not year affected perennial biomass ($F = 4.521$; df = 3,71; $P < 0.01$). Greater biomass in the mow-only compared to the control plots ($t = 3.629$; $P < 0.05$) was the only significant treatment difference observed for perennial biomass (Fig. 1c). The 3-yr average biomass of perennials in control plots was $5.6 \pm 5.6\ g \cdot m^{-2}$ (Fig. 1d), $33.8 \pm 7.0\ g \cdot m^{-2}$ with mowing alone, $17.5 \pm 7.9\ g \cdot m^{-2}$ with mowing and removal, and $25.4 \pm 15.6\ g \cdot m^{-2}$ with mowing and solarization.

Mowing treatments also significantly affected the yellow starthistle soil seedbank ($H = 17.079$; df = 3; $P < 0.001$). After 3 yr of treatment, the reservoir of yellow starthistle seeds in soil was reduced compared to control in all treatment methods (Fig. 2), with 100% reduction (no starthistle seedling emergence) in mow-only and mow/solarize treatments ($Q = 2.746$; $P < 0.05$ for both) and 92% reduction in the mow/remove treatment ($Q = 2.234$; $P < 0.05$). Differences among treatment methods in reducing seedbank viability of starthistle were not statistically significant. No significant effects of the treatments were observed on annual or perennial seedbanks.

DISCUSSION

In this study, late-season mowing proved to be effective for controlling yellow starthistle, reducing the invader to zero or near-zero levels both in aboveground biomass and the seedbank after 3 yr of repeated treatments. Our results confirmed the findings of other studies that have measured substantial reductions in starthistle infestation with late-season mowing. Using two mowings per year, Thomsen et al. (1997) achieved a reduction of seedling density of yellow starthistle of 95–98% over 3 yr of treatment; with only one mowing, reduction of density ranged from 74% to 89%. Biomass reduction with one late-season mowing ranged from 86% to 99% in the study of Benefield et al. (1999).

We were particularly interested in the effect of mowing treatments on nontarget species. A preliminary study by Rusmore (1995) found that repeated mowings in the same season diminished the presence of a native grass and a native

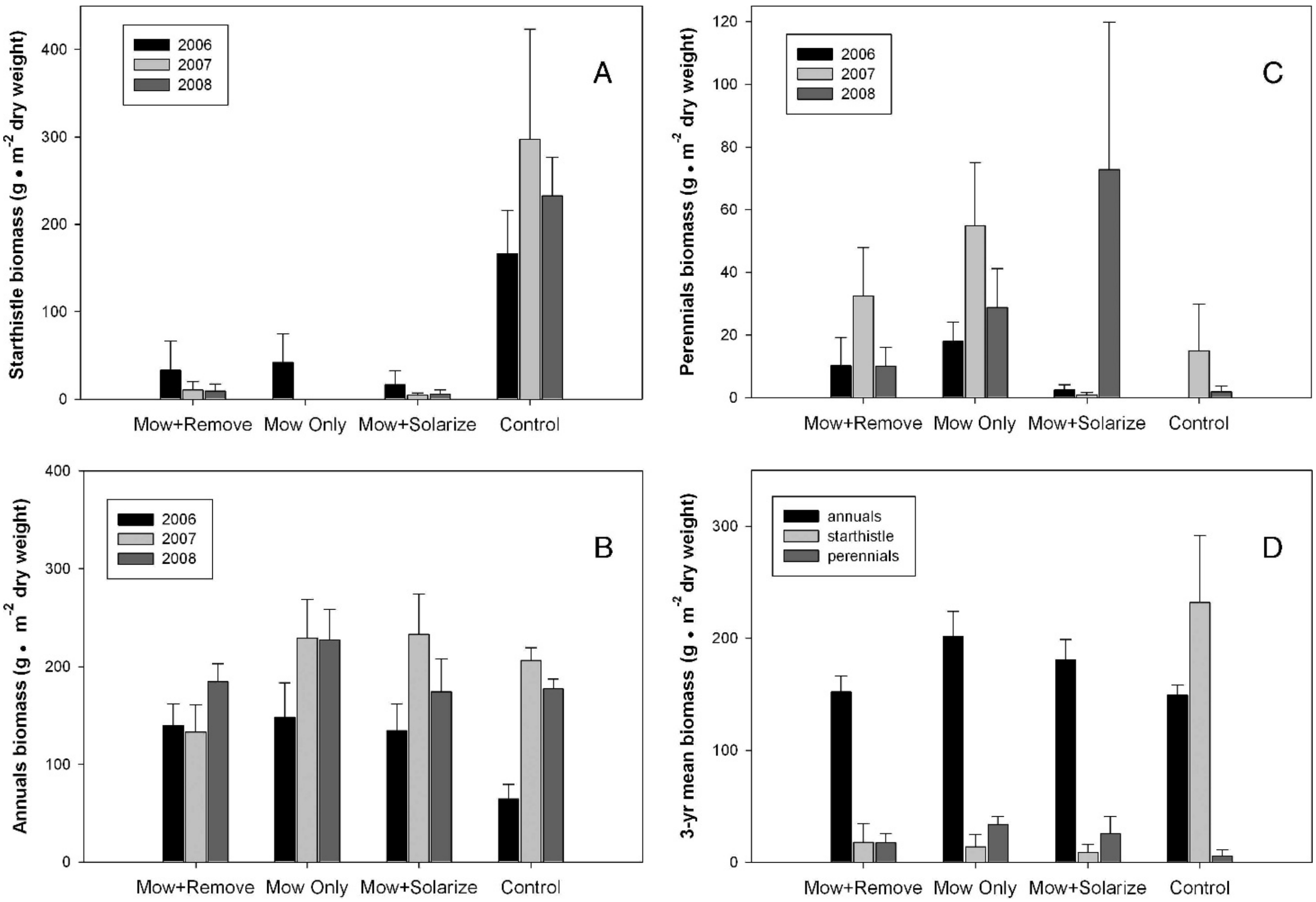

Figure 1. Biomass comparisons for three mowing treatments and control. **A,** Yearly starthistle biomass. All treatments significantly reduced starthistle biomass compared to control but were not significantly different from each other. **B,** Yearly biomass of all other annuals; 2006 had significantly lower annual biomass than other years, but treatment differences were not significant. **C,** Yearly biomass of perennial plants. Mowing alone significantly increased perennial biomass compared to control, but no other differences were significant. **D,** Three-year mean biomass values for plant groupings.

forb, but these species were also absent or decreased over time in plots where starthistle continued to invade. In our study, mowing alone significantly increased perennial biomass compared to thistle-infested plots. In the other mowing treatments, the mean perennial biomass over 3 yr was four to five times as great than in control plots, but these differences were not statistically significant. Variability among years and among plots in the same treatments was high, probably because perennial monocots in this system are patchily distributed, clump-forming species. We had anticipated that the mow/solarize treatment might decrease perennial biomass if temperatures under the tarp were high enough to kill perennials, but we did not observe this effect. Instead, the greatest harm to perennials seemed to come from starthistle itself. With respect to the perennial seedbank, no significant differences were observed, but it is noteworthy that no perennials germinated from the control plots' seed cores, while at least one seedling came up from all the other treatments.

Annual grasses and forbs are the principal spring forage in California rangelands, and their productivity is an important indicator of range quality. Yellow starthistle is thought to degrade rangelands by impeding livestock from grazing in infested areas, but few data exist on whether yellow starthistle actually decreases forage yield directly. A study of clopyralid use found that "desirable forage" quantity (i.e., all annual and perennial herbs except starthistle) increased with earlier application of herbicide and with higher rates of application (DiTomaso et al. 1999b), suggesting that starthistle plants outcompete other species for resources, reducing their yield. We found no effect of either starthistle or mowing treatments on the total annual biomass. Instead, annual biomass was strongly influenced by the year of sampling. Rainfall is a strong driver of annual biomass in California rangelands (Murphy 1970). Seedbank results mirrored biomass results for annuals, with no effect of any treatment.

In addition to effects on nontarget species, we investigated whether additional measures to reduce seed rain or kill starthistle achenes would improve control of the invader. Our results suggest that neither removal of mowed thatch nor application of solarization tarps is worthwhile as an add-on to late-season mowing. Neither method significantly improved on the mow-only treatment with regard to reducing starthistle biomass or seedbank size or increasing abundance of annual or perennial forage yield.

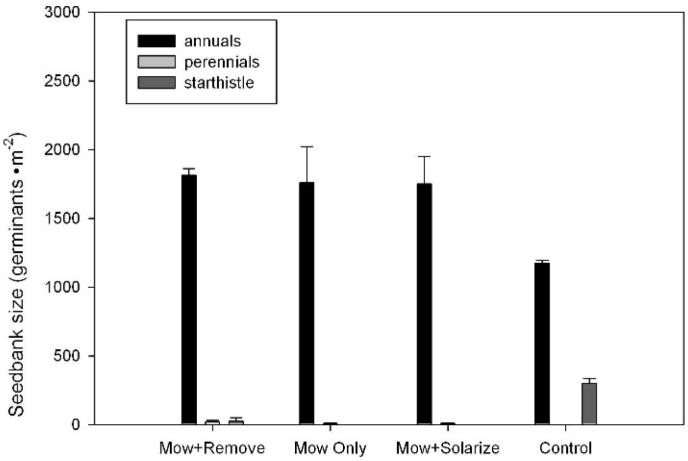

Figure 2. Seedbank size of starthistle, other annuals, and perennials after 3 yr of mechanical controls. Viable starthistle seeds were sharply reduced in all mowing treatments compared to control, but treatments were not significantly different from each other, and no effect of treatments on annual or perennial seedbanks was found.

IMPLICATIONS

This research shows that late-season mowing can effectively reduce starthistle biomass and seedbank size without adverse effects on forage vegetation. Also, mowing alone appears to be sufficient to reduce starthistle seedbanks without need for additional methods to prevent seed rain. We found an effective strategy was to mow repeatedly for 3 yr, at a height of 5 cm, in the late summer when starthistle was just beginning to flower. Managers should consider incorporating this method of mechanical control into an integrated pest management strategy, especially where repeated herbicide use might select for resistant varieties of starthistle or where terrain dictates the use of mowing equipment.

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