Late-Season Targeted Grazing of Yellow Starthistle (*Centaurea solstitialis*) with Goats in Idaho

Brianna J. Goehring, Karen L. Launchbaugh, and Linda M. Wilson*

Yellow starthistle (*Centaurea solstitialis*) is an exotic winter annual forb that is aggressively invasive and problematic in much of California, Idaho, Oregon, and Washington. Yellow starthistle control is particularly challenging in canyon rangelands where accessibility limits control options. Our objective was to evaluate the effects of late-season targeted goat grazing on yellow starthistle and nontarget grasses and forbs. A 3-yr grazing study was initiated in 2006 on a 380-ha (939 acres) canyon grassland site infested with yellow starthistle near White Bird, ID. Twenty-four paired plots were established, with each pair including a fenced subplot to exclude grazing and a similar-sized adjacent subplot that was grazed. Density of yellow starthistle plants and seedheads was assessed after grazing of each plot in all 3 yr and before grazing in the second and third years. Canopy cover of yellow starthistle, grasses, and forbs also was measured. Grazed subplots had 58% fewer yellow starthistle plants than the ungrazed controls after grazing was applied and 94% fewer seedheads after 3 yr of grazing. Cover of yellow starthistle did not differ between grazed and ungrazed subplots after grazing in 2006, whereas grazing decreased yellow starthistle cover in 2007 and 2008 by about 75%. Goat grazing had little impact on canopy cover of grasses and resident forbs, with the exception of after grazing in 2007 when there was less forb cover in grazed areas compared with ungrazed areas. Late-season (i.e., July to November) targeted goat grazing appears to be an effective way to reduce yellow starthistle plant densities at landscape scales, which creates a large window of opportunity for grazing treatment and flexibility for land and livestock managers.

Nomenclature: Yellow starthistle; *Centaurea solstitialis* L. CENSO.

Key words: *Centaurea solstitialis*, invasive plants, prescribed grazing.

Invasive plants cause tremendous ecological and economic loss on rangelands (Duncan and Jachetta 2005). Yellow starthistle (*Centaurea solstitialis* L.) is a particularly challenging invasive winter annual that is one of the most problematic and widespread plants in the United States (DiTomaso 2000), infesting almost 6,000,000 hectares in the western states (Duncan and Jachetta 2005). Major infestations exist in California, Idaho, Oregon, and Washington. Yellow starthistle has been increasing in abundance since 1970 (Maddox et al. 1985) and is spreading at an annual rate of 13 to 17% (Duncan and Jachetta 2005).

Yellow starthistle can form dense stands that are avoided by most livestock and wildlife species (Thomsen et al. 1993). Yellow starthistle creates fuel loads for wildfires (Thomsen et al. 1997) and degrades recreational value and biodiversity (Balciunas and Villegas 1999; Benefield et al. 1999). Yellow starthistle has the ability to impact community structure and function by displacing native and sometimes rare plant species, by altering wildlife populations, and by modifying fuel characteristics and soil moisture levels (Duncan and Jachetta 2005). Yellow starthistle also invades grain fields, orchards, vineyards, cultivated crops, pastures, roadsides, and wastelands and can contaminate alfalfa, cereal grains, hay, and commercial seed (Maddox and Mayfield 1985).

Yellow starthistle spreads primarily with disturbance but can also spread to undisturbed areas (Roché et al. 1994), and this accentuates the need for treatment options. A variety of control measures (mainly herbicide) successfully have controlled small infestations. However, yellow starthistle presently infests vast areas of rugged canyon rangelands where inaccessible terrain limits feasibility of

DOI: 10.1614/IPSM-D-09-00004.1

* First and second authors: Former Graduate Student and Professor, Department of Rangeland Ecology and Management, University of Idaho, Moscow, ID 83844; third author: Manager, Invasive Plant Management; British Columbia Ministry of Agriculture and Lands, Abbotsford, BC, Canada V3G2M3. Corresponding author's E-mail: klaunchb@uidaho.edu

Interpretive Summary

Yellow starthistle is a highly invasive winter annual forb that is continuing its spread in western North America. Yellow starthistle can form dense stands that are avoided by most livestock and wildlife species and can displace native plant species, alter wildlife populations, and modify fuel characteristics and soil moisture levels. A variety of control measures, including mowing and herbicide, have successfully controlled small infestations. However, yellow starthistle presently infests vast areas of rugged canyon rangelands where feasibility of some control methods are limited by accessible terrain. Targeted grazing by domestic goats could be an effective means for managing yellow starthistle in steep terrain and at landscape scales. Goats readily consume yellow starthistle seedheads that have fully developed spines, but other livestock have not been observed to consume yellow starthistle in its mature stage. Our research shows that goats will graze yellow starthistle when the plant is in full spine, and that a single, late-season grazing treatment reduced yellow starthistle populations. This creates a large window of opportunity for grazing treatment and flexibility for land and livestock managers at the landscape scale because grazing can be applied at any stage of yellow starthistle growth, although grazing earlier in the season will require follow-up grazing to treat regrowth.

some control methods. Targeted grazing using domestic goats might be an effective means for managing yellow starthistle in steep terrain and at landscape scales. Targeted grazing with livestock as a weed management tool has been gaining popularity and has application for many weedy species. For example, goat and sheep grazing can reduce plant densities of spotted knapweed (*Centaurea stoebe* L.; Olson et al. 1997; Williams and Prather 2006). Sheep and cattle have been used successfully to control leafy spurge (*Euphorbia esula* L.; Jacobs et al. 2006; Lacey et al. 1984; Olson and Wallander 1998).

Goats readily consume yellow starthistle seedheads that have fully developed spines (personal observation). Other livestock have not been observed to consume yellow starthistle in its mature stage (Hovde 2006). Research that has focused on target grazing yellow starthistle has been conducted in small paddocks (Hovde 2006; Thomsen et al. 1989, 1993). Little is known about the usefulness of target grazing yellow starthistle at the landscape scale.

Our research objective was to determine whether targeted goat grazing is a viable tool for yellow starthistle management at a landscape scale. Specifically, we evaluated the effect of late-season goat grazing on: (1) plant and seedhead density of yellow starthistle, and (2) canopy cover of yellow starthistle and associated plants in the community.

Materials and Methods

Study Area. A three-year study was conducted from 2006 to 2008 on Bentz Ridge (45°45′N, 116°17′W; elev. 496 to 745 m [1627 to 2444 ft]) just northeast of White Bird, ID The land was managed by the U.S. Forest Service. The site had a south-facing aspect with slopes ranging from 20 to 35°. Soils at the site were shallow loam to silt loam (Johnson and Simon 1987). The study area received annual precipitation of 54.4 to 58.8 cm (21.4 to 23.1 inches) with a 60-yr average of 23.2 in, and most of this occurred in the spring and the fall (Western Regional Climate Center 2008). Winter precipitation was slightly below the long-term average for all years of the study. The initial year experienced slightly below-average fall precipitation and then slightly above-average spring precipitation whereas summer months of all 3 yr were drier than normal. The second year had above-average precipitation in fall 2006, but spring and summer 2007 were substantially drier than average for all the growing season. The spring of 2008 was both wetter and cooler than the other study years and the long term average.

The historic plant community was a bluebunch wheatgrass [*Pseudoroegneria spicata* (Pursh.) A. Löve]/ Sandberg bluegrass (*Poa secunda* J. Presl) plant association (Johnson and Simon 1987). However, this rangeland site was in fairly degraded condition as indicated by limited cover of perennial grasses and dominance of exotic annual plants. The site was selected for its relatively high cover of yellow starthistle (37%). Other vegetation present was perennial and annual grasses (22%) and forbs (excluding yellow starthistle, 13%). Annual grass present at the site was predominantly downy brome (*Bromus tectorum* L.), with lesser coverage of medusahead [*Taeniatherum caput-medusae* (L.) Nevski], wild oat (*Avena fatua* L.), field brome (*Bromus arvensis* L.), and rattlesnake brome (*Bromus briziformis* Fisch. & C. A. Mey.). Perennial grasses comprised less than 4% of the grasses present and mainly included bluebunch wheatgrass and Sandberg bluegrass. Weedy exotic annual forbs besides yellow starthistle were fiddleneck (*Amsinckia* sp.), field pennycress (*Thlaspi arvense* L.), redstem filaree [*Erodium cicutarium* (L.) L'Hér Ex Aiton], tumble mustard (*Sisymbrium altissimum* L.), and yellow salsify (*Tragopogon dubius* Scop.). Perennial forbs present included arrowleaf balsamroot [*Balsamorhiza sagittata* (Pursh) Nutt.], biscuitroot (*Lomatium* spp.), lupine (*Lupinus* spp.), field bindweed (*Convolvulus arvensis* L.), penstemon (*Penstemon* spp.), and common yarrow (*Achillea millefolium* L.).

Twenty-four paired plots were randomly established in six areas across 380 ha on Bentz Ridge in the summer of 2006. These areas varied in slope, but exceptionally steep or rocky areas were avoided. At each plot, we marked two subplots of similar vegetation and topography adjacent to each other. One subplot was then randomly selected as the ungrazed control and fenced, and the other remained unfenced to be the grazed treatment subplot. Each fenced subplot was a 15 by 7 m [49 by 23 ft] exclosure constructed from ElectroNet™ temporary fencing (Premier One Supplies, Washington, IA). These ungrazed exclosures were maintained in the same location each year of the study. Because these paired plots occurred in a single pasture, this is a classic case of pseudoreplication (Hurlbert 1984). The statistical implications of this research were limited to the yellow starthistle response on south-facing slopes on Bentz Ridge, Idaho.

Treatment Application. Prescriptive Livestock Services, a grazing service in White Bird, ID, managed the goat grazing for the duration of this study. In the first year of the study, grazing was applied to the study area twice within the season because Thomsen et al. (1993) demonstrated that follow-up treatments within a season were necessary to treat regrowth of yellow starthistle. Also, it was widely thought that livestock, including goats, avoid yellow starthistle when it is in full spine. However, after observing in Year 1 that goats consumed fully developed yellow starthistle seedheads, we adjusted our methods so that goat grazing was only applied once late-season in Years 2 and 3. In Year 1, 1,233 yearling goats grazed about 405 ha in 68 d (June 25 to August 31, 2006). Grazing occurred a second time October 10 to November 10 (total stocking rate of 221 goat days ha^{-1} in Year 1, assuming one yearling goat is 75% of one adult goat). In Year 2, 1,657 dry female goats grazed about 648 ha in 42 d (July 27 to September 10, 2007; 81 goat days ha^{-1}). For Year 3, 1,706 dry female goats grazed about 809 ha in 52 d (August 8 to September 28, 2008; 82 goat days ha^{-1}). The goats used were of predominantly Boer and Boer crossbreeds that had experience grazing yellow starthistle and foraging on rugged terrain.

Vegetation Assessments. After goat grazing was applied in Year 1, the number of yellow starthistle plants and mature seedheads and percent canopy cover of yellow starthistle, grass, and forbs were assessed with five quadrats (25 by 50 cm) along a 10-m pace transect in each grazed and ungrazed subplot. Transects were re-established in Year 2 and permanently marked to facilitate examining the same quadrat area before and after grazing. We did not repeatedly examine the same quadrats across years of the study. Vegetation assessments were conducted before and after grazing was applied in Years 2 and 3. Eight and 10 quadrats were measured from each subplot in Years 2 and 3, respectively.

Statistical Analysis. All statistical analyses were conducted using SAS software (SAS 2002). Data collected after goat grazing (2006, 2007, and 2008) were analyzed separately from data collected before grazing (2007 and 2008). Variables in each dataset were densities of yellow starthistle plants and yellow starthistle seedheads, and canopy cover of yellow starthistle, grass, and forbs. Plant and seedhead density before grazing and plant density after grazing were square-root transformed, and seedhead density after grazing was logarithmically transformed to satisfy assumptions of normality (Steel and Torrie 1980). Forb cover collected both before and after grazing and yellow starthistle cover after grazing were arc-sine transformed (Steel and Torrie 1980) to obtain normal distributions. Data were then analyzed with a completely randomized mixed model analysis of variance. Each variable was analyzed for differences among years, between grazed and ungrazed subplots, and for a treatment-by-year interaction. Variables that produced treatment-by-year interactions were further analyzed separately by year. Differences were considered significant at an α level of $P < 0.05$.

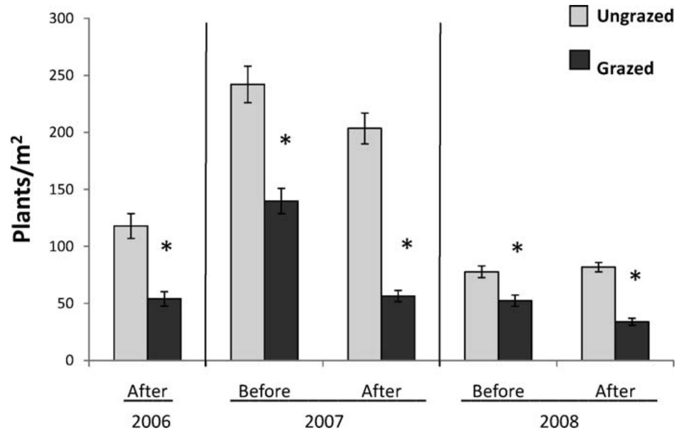

Figure 1. Density of yellow starthistle plants with standard error bars in grazed and ungrazed subplots after goat grazing in 2006 and before and after grazing in 2007 and 2008, in a yellow starthistle-dominated site in north central Idaho. Asterisks indicate significant differences between grazed and ungrazed subplots.

Results

Grazing Effects on Yellow Starthistle. Yellow starthistle density after grazing treatments in grazed and ungrazed plots differed among years (treatment-by-year interaction, $P = 0.003$), thus grazing effects were analyzed by year. Grazing resulted in lower yellow starthistle plant density in grazed compared with ungrazed control subplots ($P < 0.001$ for each year; Figure 1). The treatment-by-year interaction was likely because of the greater difference in plant number between the grazed and ungrazed subplots found in 2007 compared with 2006 or 2008. Even before the grazing treatment was applied in 2007 and 2008, fewer yellow starthistle plants were found in grazed subplots compared with ungrazed controls ($P < 0.001$; Figure 1). More plants were present in the study area before grazing in 2007 than 2008 ($P < 0.001$), but there was no treatment-by-year interaction ($P = 0.104$).

Grazing reduced yellow starthistle seedhead density compared with the ungrazed control ($P < 0.001$; Figure 2)

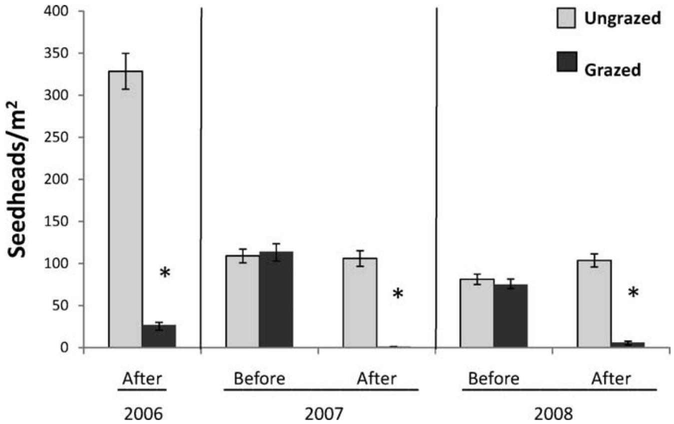

Figure 2. Density of yellow starthistle seedheads with standard error bars in grazed and ungrazed subplots after goat grazing in 2006 and before and after grazing in 2007 and 2008. Asterisks indicate significant differences between grazed and ungrazed subplots.

with no treatment-by-year interaction (P = 0.254). The seedhead density was highest in 2006 (P < 0.001) with lower density observed in 2007 or 2008, which were similar to each other. Seedhead density before grazing was similar inside and outside the exclosures (P = 0.331; Figure 2). More seedheads were present in the study area before grazing in 2007 than 2008 (P = 0.003) but there was no treatment-by-year interaction (P = 0.556).

The effect of grazing on yellow starthistle canopy cover depended on the year (treatment-by-year interaction; P = 0.032 after grazing; P = 0.042 before grazing; Figure 3), so grazing effects were examined within years. Cover of yellow starthistle did not differ between grazed and ungrazed subplots after grazing in 2006 (P = 0.072), whereas grazed subplots had lower yellow starthistle cover than the ungrazed controls in 2007 and 2008 (P < 0.001 for both years; Figure 3). Yellow starthistle cover was lower in grazed areas compared with the ungrazed controls before grazing occurred in 2007 (P = 0.005), but grazed and ungrazed subplots had similar yellow starthistle cover before grazing in 2008 (P = 0.212; Figure 3).

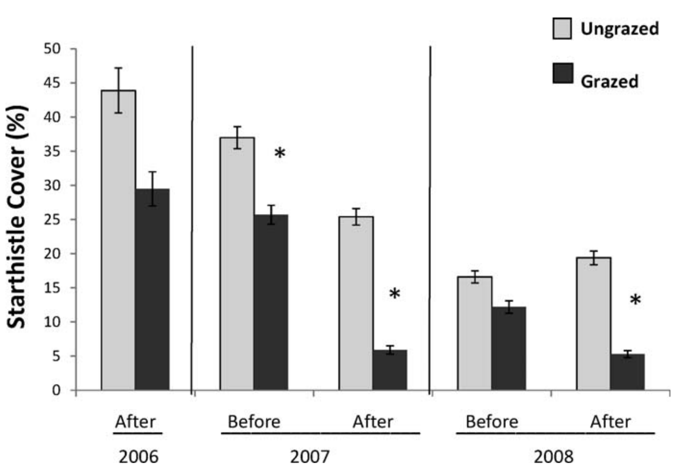

Figure 3. Yellow starthistle canopy cover with standard error bars in grazed and ungrazed subplots after goat grazing in 2006 and before and after grazing in 2007 and 2008. Asterisks indicate significant differences between grazed and ungrazed subplots.

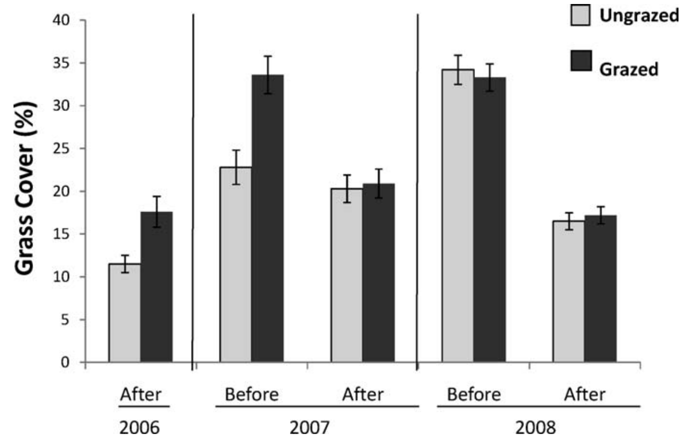

Figure 4. Grass canopy cover with standard error bars in grazed and ungrazed subplots after goat grazing in 2006 and before and after grazing in 2007 and 2008. Asterisks indicate significant differences between grazed and ungrazed subplots.

Grass and Forb Cover Response. Grass canopy cover (annual and perennial) after grazing was similar for grazed and ungrazed subplots (P = 0.063) and over the years (P = 0.142; Figure 4) with no treatment-by-year interaction (P = 0.457). Canopy cover of forbs (excluding yellow starthistle) after grazing in grazed and ungrazed subplots differed among years (treatment-by-year interaction, P < 0.001); thus, grazing effects were analyzed by year. Forb cover for grazed subplots was similar to the ungrazed exclosures in 2006 (P = 0.961) and 2008 (P = 0.179; Figure 5). In 2007, however, grazing reduced forb cover compared with the ungrazed exclosures (P < 0.001).

We observed a treatment-by-year interaction for grass canopy cover before the grazing treatment was applied (P = 0.029), but when analyzed by year, we found that grazed and ungrazed subplots had similar grass cover for both 2007 (P = 0.118) and 2008 (P = 0.986; Figure 4). Forb canopy cover before grazing was similar for grazed and ungrazed subplots (P = 0.497; Figure 5). There was less total forb cover in 2007 than in 2008 (P < 0.001), but there was no treatment-by-year interaction (P = 0.547).

Discussion

Impacts of Targeted Grazing to Yellow Starthistle. Goats uniformly and thoroughly grazed yellow starthistle as indicated by the prominent lack of seedheads or foliage throughout most of the study area after grazing. In this

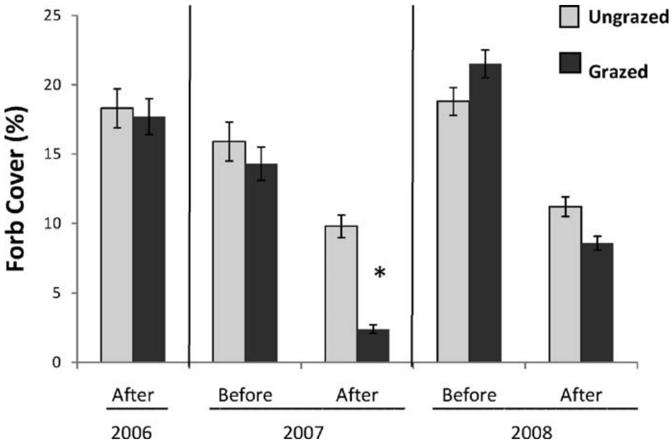

Figure 5. Forb canopy cover with standard error bars in grazed and ungrazed subplots after goat grazing in 2006 and before and after grazing in 2007 and 2008. Asterisks indicate significant differences between grazed and ungrazed subplots.

study, goats grazed yellow starthistle in late season when plants were in full spine and when soil moisture was inadequate to support regrowth after grazing. We observed no evidence of regrowth when we conducted vegetation assessments after the grazing treatment. Other studies have demonstrated that timing of grazing is critical for reducing yellow starthistle growth and reproduction (Hovde 2006; Thomsen et al. 1989, 1993). Hovde (2006) determined that when yellow starthistle was grazed in early stages of its growth (i.e., rosette and bolting), the plant responded with sufficient regrowth so that plant density, seedhead production, and yellow starthistle cover were greater in grazed pastures than in the ungrazed controls at the end of the season. Therefore, early-season grazing of yellow starthistle required a second grazing treatment in the same season to target regrowth (Thomsen et al. 1993).

After just 1 yr of treatment, we measured fewer yellow starthistle plants where goats had grazed the previous year. This was unexpected because yellow starthistle responses following initial treatment often are unnoticeable because of the established seedbank (Joley et al. 1992; Thomsen et al. 1997). Furthermore, grazing causes soil disturbance, increases sunlight penetration by removing canopy cover, and removes litter, which can increase germination and seedling survival (Gelbard and Harrison 2005; Roché and Thill 2001). Targeted goat grazing in our study reduced seedhead densities 95% in grazed areas compared with ungrazed controls. Goats in our study were ingesting viable yellow starthistle seeds, but only about 3% of recovered seeds were viable following passage through the goat's digestive tract (Goehring 2009). Other weed seed species have also experienced low survival and substantial reductions in viability following ingestion (Lacey et al. 1992; Thill et al. 1986; Wallander et al. 1995). For example, 11 and 4% of spotted knapweed seeds fed to sheep were recovered from feces in two trials, and viability of the recovered seeds ranged between 0 and 26% (Wallander et al. 1995). Seed destruction in the goat digestive tract might also have contributed to decreased seed rain and might explain why we measured decreased yellow starthistle densities before grazing was applied in 2007 and 2008, despite conditions that seemed to promote germination and seedling recruitment (e.g., disturbance, reduced cover, sufficient moisture availability).

Seedheads removed by goats in our study could have reduced seed abundance to a level that resulted in reduced seedling establishment the subsequent year. We contend that grazing reduces the yellow starthistle seedbank similar to the effects of other treatments such as prescribed fire (DiTomaso et al. 1999). Although we lack knowledge of yellow starthistle seedbank dynamics in our study area, if goat grazing is reducing seed rain of yellow starthistle, continued seasons of goat grazing should result in further declines of yellow starthistle plant density.

We observed no difference in seedhead density between the control and grazed areas before grazing was applied in 2007 and 2008 despite reduced plant densities. This agrees with Uygur and colleagues (2004) who noted that when yellow starthistle plant densities were low, seedhead production per plant can increase to result in relatively constant seedhead production.

Impacts of Targeted Grazing to Nontarget Vegetation. Goat grazing had few effects on canopy cover of either grasses or forbs in our study. One exception was in 2007 where forb cover was lower in the grazed areas compared with the control after grazing was applied. Natural forb recruitment might have been low because of the combined effects of the dry year (spring and summer precipitation was 28% below long-term average) and grazing and trampling by goats. Alternatively, forbs were grazed more by goats for that year. However, goat grazing of yellow starthistle occurred when most other forbs and grasses were dormant or senesced and therefore not highly susceptible to grazing impacts (Trlica 2006).

The lack of difference in nontarget vegetation cover in grazed areas compared with the ungrazed control suggests that this nontarget vegetation was not preferred by goats. The dominant plants on Bentz Ridge besides yellow starthistle were annual grasses, notably downy brome. Perennial grasses were not abundant enough on our study site for us to determine how targeted goat grazing of yellow starthistle might have affected these plants.

Variations of Yellow Starthistle over Time. Yellow starthistle cover and density varied across years, irrespective of grazing treatment. For example, yellow starthistle cover in ungrazed plots decreased over the 3 yr of the study in both grazed and ungrazed plots. Seedhead densities were markedly lower in 2007 and 2008 than in 2006. Yellow starthistle recruitment, seedling survival, and reproduction are highly dependent on the timing and amount of rainfall (Joley et al. 2003), but density and cover of yellow starthistle in this study were not readily connected with precipitation patterns. Yellow starthistle plant density was higher in 2007 than either 2006 or 2008. This might be due to the above-average precipitation in fall 2006, or this might reflect the oscillating pattern that has been noted for yellow starthistle where a year of high plant density is followed by a year of low plant density (Enloe et al. 2004; Hovde 2006; Uygur et al. 2004).

In its native range, Uygur and colleagues (2004) suggested that the cyclic nature sometimes observed in yellow starthistle might be caused by the presence of natural enemies: yellow starthistle can rapidly build up its population density, and over time natural enemies will also increase in density until yellow starthistle reproductive output is suppressed. This also might account for the large decrease observed in seedhead density from 2006 to 2007 and 2008. Two seedhead-feeding insects of yellow starthistle, the yellow starthistle hairy weevil (*Eustenopus villosus*) and the yellow starthistle flower weevil (*Larinus curtus*), appeared to be abundant throughout the study area on Bentz Ridge, and many seedheads appeared to be damaged; however, data about these weevils and their impact to yellow starthistle at this site were not collected. Attack by yellow starthistle-feeding insects can substantially reduce seed production (Pitcairn et al. 2000; Wallace et al. 2008). At a study site in California, attack on yellow starthistle seedheads by yellow starthistle-feeding insects decreased seed production from 13,839 to 3,802 seeds m^{-2} over 4 yr, and seedling density dropped from 897 to 234 seedlings m^{-2} (Pitcairn et al. 2000). Despite these declines, no decrease was observed in adult plant densities for that year in the study; however, the authors predicted a decline in adult plant density in future years if the decline in seed production and seedling recruitment continue while biological control agent densities continue to increase.

Management Implications. In our study, late-season goat grazing reduced plant and seedhead densities of yellow starthistle with few impacts to grasses or other forbs. Targeted grazing offers the dual purpose of not only controlling yellow starthistle but also utilizing the forage value of yellow starthistle. It is difficult to assess the value of targeted grazing for restoration of our study area or similar sites.

Restoration of a yellow starthistle-infested site would include both decreasing yellow starthistle abundance and increasing native species abundance. In our study, late-season goat grazing reduced plant and seedhead densities of yellow starthistle with few discernible impacts to grasses or other forbs; however, we were unable to detect a positive shift (specifically, an increase in native plant species) in the vegetation composition of the study area.

It is difficult to assess the value of targeted grazing for restoration of our study area or similar sites. After 64 yr of rest, natural revegetation of a disturbed site in southeastern Washington resulted in a predominantly perennial grass community on the north-facing slope of the site, whereas the south-facing slope was dominated with downy brome and yellow starthistle (Dillon 1967). This observation could have important implications for management of yellow starthistle; shifting the balance of competition in favor of perennial species through targeted grazing might not be a realistic goal for south-facing infested sites such as Bentz Ridge in our study. Seeding of perennial grass species would be a necessary part of a restoration project for Bentz Ridge because the low abundance of perennial grasses in the study area suggests that the seedbank of perennial grasses likely is small.

Yellow starthistle can recover rapidly from small populations and reduced seedbanks. For example, Kyser and DiTomaso (2002) found that 3 yr of prescribed burning drastically reduced yellow starthistle cover and the size of the seedbank at an infested study site, but within 4 yr the burned areas had nearly returned to their preburn state. A cessation of goat grazing on Bentz Ridge after 3 yr of grazing likely will result in a return to pregrazing yellow starthistle cover and density.

Infested canyon rangelands with limited accessibility pose a special challenge for management. Targeted goat grazing offers two distinctive advantages for managing such infested areas: (1) goats can easily navigate the rugged terrain of these canyonlands, and (2) goats will graze yellow starthistle throughout most of its life cycle. Our research clearly shows that goats will even graze yellow starthistle when the plant is in full spine. Multiple grazing treatments or a single late-season grazing treatment can reduce yellow starthistle populations. This creates a large window of opportunity for grazing treatment and flexibility for land and livestock managers. A long-term commitment to targeted grazing likely will be necessary to accomplish landscape management goals.

Acknowledgments

We gratefully acknowledge the U.S. Forest Service, the University of Idaho David Little Range Livestock Endowment, the American Sheep Industry Association, and the Idaho County Weed Board for funding of this research.

Literature Cited

Balciunas, J. and B. Villegas. 1999. Two new seed head flies attack yellow starthistle. Calif. Agric. 53:8–11.

Benefield, C. B., J. M. DiTomaso, G. B. Kyser, S. B. Orloff, K. R. Churches, D. B. Marcum, and G. A. Nader. 1999. Success of mowing to control yellow starthistle depends on timing and plant's branching form. Weed Sci. 48:255–265.

Dillon, C. C. 1967. Exposure may influence grassland establishment. J. Range Manag. 20:117–118.

DiTomaso, J. M. 2000. Invasive plants in rangelands: species, impacts, and management. Weed Sci. 48:255–265.

DiTomaso, J. M., G. B. Kyser, and M. S. Hastings. 1999. Prescribed burning for control of yellow starthistle (*Centaurea solstitialis*) and enhanced native plant diversity. Weed Sci. 47:233–242.

Duncan, C. A. and J. J. Jachetta. 2005. Introduction. Pages 1–7 *in* C. A. Duncan and J. K. Clark, eds. Invasive Plants of Range and Wildlands and their Environmental, Economic, and Societal Impacts. Lawrence, KS: Weed Science Society of America.

Enloe, S. F., J. M. DiTomaso, S. B. Orloff, and D. J. Drake. 2004. Soil water dynamics differ among rangeland plant communities dominated by yellow starthistle (*Centaurea solstitialis*), annual grasses, or perennial grasses. Weed Sci. 52:929–935.

Gelbard, J. L. and S. Harrison. 2005. Invasibility of roadless grasslands: an experimental study of yellow starthistle. Ecol. Appl. 15: 1570–1580.

Goehring, B. J. 2009. The effects of targeted grazing of yellow starthistle by domestic goats in northern Idaho and an examination of seed survival in the ruminant digestive tract. M. S. Thesis. Moscow, ID: University of Idaho. 65 p. http://www.cnr.uidaho.edu/range/GraduateThesesandDissertation/Goehring_2009.pdf. Accessed: May 23, 2009.

Hovde, E. M. 2006. Grazing by cattle and sheep affect yellow starthistle. M. S. Thesis. Moscow, ID: University of Idaho. 69 p. http://www.cnr.uidaho.edu/range/GraduateThesesandDissertation/Hovde_2006.pdf. Accessed: October 24, 2007.

Hurlbert, S. H. 1984. Pseudoreplication and the design of ecological field experiments. Ecol. Monogr. 54:187–211.

Jacobs, J. S., R. L. Sheley, and J. J. Borkowski. 2006. Integrated management of leafy spurge-infested rangeland. Rangeland Ecol. Manag. 59:475–482.

Johnson, C. G. Jr. and S. A. Simon. 1987. Pages 97–101 *in* Plant Associations of the Wallowa–Snake Province: Wallowa–Whitman National Forest. U.S. Forest Service, USDA, Report No. R6-ECOL-TP-255A-86.

Joley, D. B., D. M. Maddox, S. E. Schoenig, and B. E. Mackey. 2003. Parameters affecting germinablility and seed bank dynamics in dimorphic achenes of *Centaurea solstitialis* in California. Can. J. Bot. 81:993–1007.

Joley, D. B., D. M. Maddox, D. M. Supkoff, and A. Mayfield. 1992. Dynamics of yellow starthistle (*Centaurea solstitialis*) achenes in the field and laboratory. Weed Sci. 40:190–194.

Kyser, G. B. and J. M. DiTomaso. 2002. Instability in a grassland community after the control of yellow starthistle (*Centaurea solstitialis*) with prescribed burning. Weed Sci. 50:648–657.

Lacey, C. A., R. W. Kott, and P. L. Fay. 1984. Ranchers control leafy spurge. Rangelands 6:202–204.

Lacey, J. R., R. Wallander, and K. Olson-Rutz. 1992. Recovery, germinability, and viability of leafy spurge (*Euphorbia esula*) by sheep. Weed Technol. 6:599–602.

Maddox, D. M. and A. Mayfield. 1985. Yellow starthistle infestations are on the increase. Calif. Agric. 39:10–12.

Maddox, D. M., A. Mayfield, and N. H. Poritz. 1985. Distribution of yellow starthistle (*Centaurea solstitialis*) and Russian knapweed (*Centaurea repens*). Weed Sci. 33:315–327.

Olson, B. E., R. T. Wallander, and J. R. Lacey. 1997. Effects of sheep grazing on a spotted knapweed-infested Idaho fescue community. J. Range Manag. 50:386–390.

Olson, B. E. and R. T. Wallander. 1998. Effect of sheep grazing on a leafy spurge-infested Idaho fescue community. J. Range Manag. 51: 247–252.

Pitcairn, M. J., D. M. Woods, D. B. Joley, C. E. Turner, and J. K. Balciunas. 2000. Population buildup and combined impact of introduced insects on yellow starthistle (*Centaurea solstitialis* L.) in California. Pages 747–751 *in* N. R. Spencer, ed. Proceedings of the X International Symposium on Biological Control of Weeds. Bozeman, MT: Montana State University.

Roché, B. F. Jr., C. J. T. Roché, and R. C. Chapman. 1994. Impacts of grassland habitat on yellow starthistle (*Centaurea solstitialis*) invasion. Northwest Sci. 86:86–96.

Roché, C. T. and D. C. Thill. 2001. Biology of common crupina and yellow starthistle, two Mediterranean winter annual invaders in western North America. Weed Sci. 49:439–447.

SAS Institute. 2002. Statistical Analysis System for Windows, Release 9.1. Cary, NC: SAS Institute, Inc.

Steel, R. G. and J. H. Torrie. 1980. Principles and Procedures of Statistics: A Biometrical Approach. 2nd ed. New York, NY: McGraw-Hill Book Company.

Thill, D. C., D. L. Zamora, and D. L. Kambitsch. 1986. The germination and viability of excreted common crupina (*Crupina vulgaris*). Weed Sci. 34:237–241.

Thomsen, C. D., W. A. Williams, M. R. George, W. B. McHenry, F. L. Bell, and R. S. Knight. 1989. Managing yellow starthistle on rangeland. Calif. Agric. 43:4–7.

Thomsen, C. D., W. A. Williams, M. Vayssiéres, F. L. Bell, and M. R. George. 1993. Controlled grazing on annual grassland decreases yellow starthistle. Calif. Agric. 47:36–40.

Thomsen, C. D., M. P. Vayssiéres, and W. A. Williams. 1997. Mowing and subclover plantings suppress yellow starthistle. Calif. Agric. 51: 15–20.

Trlica, M. J. 2006. Grass Growth and Response to Grazing. Natural Resource Fact Sheet. No. 6.108. http://www.ext.colostate.edu/pubs/natres/06108.pdf. Accessed: December 28, 2009.

Uygur, S., L. Smith, F. Uygur, M. Cristofaro, and J. Balciunas. 2004. Population densities of yellow starthistle (*Centaurea solstitialis*) in Turkey. Weed Sci. 52:746–753.

Wallace, J. M., L. M. Wilson, and K. L. Launchbaugh. 2008. The effect of targeted grazing and biological control on yellow starthistle (*Centaurea solstitialis*) in canyon grasslands of Idaho. Rangeland Ecol. Manag. 61:314–320.

Wallander, R. T., B. E. Olson, and J. R. Lacey. 1995. Spotted knapweed seed viability after passing through sheep and mule deer. J. Range Manag. 48:145–149.

Western Region Climate Center. 2008. Idaho Climate Summaries. Grangeville, Idaho (103771) weather station. http://www.wrcc.dri.edu/summary/. Accessed: December 31, 2008.

Williams, S. and T. Prather. 2006. Goats: a tool for controlling spotted knapweed. Journal of Extension.44, Article 5RIB6. http://www.joe.org/joe/2006october/rb6.php. Accessed: May 20, 2009.

Received July 13, 2009, and approved February 11, 2010.