Research

Control of Medusahead (*Taeniatherum caput-medusae*) Using Timely Sheep Grazing

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Medusahead is among the most invasive grasses in the western United States. Selective control of this noxious winter annual grass is difficult in California grasslands, as many other desirable annual grasses and both native and nonnative broadleaf forbs are also important components of the rangeland system. Intensive grazing management using sheep is one control option. This study was designed to determine the optimal timing for sheep grazing on heavily infested medusahead sites, and to evaluate the changes in species composition with different grazing regimes. Midspring (April/May) grazing reduced medusahead cover by 86 to 100% relative to ungrazed plots, regardless of whether it was used in combination with early spring or fall grazing. Early spring (March) or fall (October to November) grazing, alone or in combination, was ineffective for control of medusahead. In addition, midspring grazing increased forb cover, native forb species richness, and overall plant diversity. At the midspring grazing timing, medusahead was in the "boot" stage, just prior to exposure of the inflorescences. The success of this timely grazing system required high animal densities for short periods. Although this approach may be effective in some areas, the timing window is fairly narrow and the animal stocking rates are high. Thus, sheep grazing is unlikely to be a practical solution for management of large medusahead infestations.

Nomenclature: Medusahead, *Taeniatherum caput-medusae* (L.) Nevski ELYCA.

Key words: Cultural control, grassland, rangeland, timing.

Medusahead [*Taeniatherum caput-medusae* (L.) Nevski] is an invasive winter annual grass of Mediterranean origin. It is well adapted to the semi-arid climates of the western United States. First introduced to Oregon as a seed contaminant around 1887 (George 1994, Young 1992), it spread rapidly north into Washington, south into California, and east into the Great Basin and other western states. It continues to expand its range by about 12% per year and recently was estimated to infest over 950,000 ha (2.4 million ac) in the 17 western states (Duncan and Clark 2005). In California, medusahead occupies more than a million acres of annual-dominated grassland, oak woodland, and chaparral communities.

Medusahead is an aggressive species with the ability to change the structure and function of grassland ecosystems. It not only increases the fire frequency within an area, but can also lead to substantial litter accumulation that suppresses the establishment of native or other desirable species (Kyser et al. 2007). Its litter decomposes slowly owing to the high silica content (> 10% dry weight) in plant tissues (Bovey et al. 1961; Hironaka 1994). Young (1992) hypothesized that medusahead litter accumulation was the greatest threat to plant biodiversity in the Great Basin.

At early stages of development, the protein content of medusahead was reported to be higher than that of many other annual grass species, but good forage quality did not persist later in the season (Lusk et al. 1961). Mature medusahead plants with high silica content have poor forage value, and heavy infestations can reduce rangeland livestock forage by 75 to 80% (Hironaka 1961; George 1994).

Like most other winter annual grasses, medusahead germinates in the fall, and rapidly develops its root system

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Interpretive Summary

Medusahead is an exotic winter annual grass that infests about 1 million ha (2.5 million acres) of western rangeland. Although prescribed burning can be successfully used to control medusahead under some circumstances, it often poses too great a risk to the environment and to human health. Some herbicides have been shown to be effective, but can be expensive and do not provide selective control in California grasslands comprised of other desirable nonnative annual grasses. Intensive grazing management using sheep is another possible control option, but little is known of the optimum timing and the effects of grazing on other components of the vegetation. In this study, we showed that midspring (April to May) high density grazing gave excellent control, whereas early spring (March) and fall (October to November) grazing were not effective for control of medusahead. Furthermore, midspring grazing just before flowering resulted in increased broadleaf cover, native species richness, and total plant diversity. In some situations, particularly small infestations, this technique could prove to be very effective. However, its use is limited because it requires high animal densities for short periods at a precise time. The narrow timing window for grazing (April to May), in combination with the very high stocking rates, may prohibit this approach in areas where medusahead infestations are extensive.

during the winter (Sheley et al. 1993). However, while most winter annual grasses complete their life cycle by late spring in the drier Mediterranean climates that are characteristic of much of California, seed maturation and disarticulation in medusahead does not occur until June and continues through most of the summer.

Few options exist for selectively removing undesirable annual grasses from grasslands. While herbicides (Monaco et al. 2005) and prescribed burning (Furbush 1953; Murphy and Lusk 1961) have been successful in some cases, they can be inconsistent (e.g., Kyser et al. 2007; Young et al. 1972), cost prohibitive, or difficult to implement due to local restrictions. Another potential option is grazing management. In early studies using sheep grazing, Lusk et al. (1961) found that heavy spring grazing reduced medusahead stands in summer. In a study designed to determine the effects of grazing management on beef production, George et al. (1989) found that intensive grazing (2.2 to 2.6 ha/500 kg [2.5 to 3 ac/500 lb] calf) over the entire season significantly reduced medusahead cover from 45 to only 10%.

In California grasslands, grazing influences the amount of residual plant litter on the soil surface at the beginning of the growing season. This can have important indirect effects on germination and seedling establishment (Heady 1956; Facelli and Pickett 1991). Part of the reduction in medusahead reported by George et al. (1989) is attributed to thatch depletion by 2 yr of heavy grazing during winter and spring. Because thatch reduction allows competing species to increase, heavy grazing usually results in increased forb cover and decreased grass cover (McDougald et al. 1991). Under light to moderate levels of grazing, many native forbs can increase in cover and frequency (Hayes and Holl 2003). In contrast, grazing exclusion or minimal grazing during the growing season in California grasslands can lead quickly to grass dominance and reductions in native and exotic legumes (*Trifolium* spp. and *Medicago* spp.) and filaree (*Erodium* spp.) (Bentley and Talbot 1951; Biswell 1956; Freckman et al. 1979; Jones and Evans 1960).

In this study, effects of intensive sheep grazing were evaluated at two stages of medusahead development, over a 2-yr period, to determine the optimal grazing timing for medusahead reduction. This study was also designed to detect changes in species composition in response to grazing timing and medusahead reduction. The goal was to develop an effective method of medusahead control in areas where the implementation of sheep grazing is practical.

Materials and Methods

Trials were conducted at the Bobcat Ranch in the western foothills of the Sacramento Valley near Winters, CA (Yolo County). This area has a Mediterranean climate with approximately 580 mm (23 in) mean annual precipitation, mostly in the cool season. The ranch (at ~90 m elevation) is annual grassland dominated by medusahead, mixed with blue oak woodland. The soils are Corning gravelly loam (site 1) and Positas gravelly loam (site 2), both brown gravelly loam soils 11 to 14 in thick over clay subsoil, on shallow slopes. The 2002 (site 1) and 2003 (site 2) field sites, ~250 m apart, were both heavily infested with medusahead. Five grazing regimes were applied at each site, in a randomized complete block design with eight replications, for a total of 40 plots in each site. Plots were 10 by 10 m with 2-m buffer strips. Treatments included (1) ungrazed control, (2) grazing in early spring and fall, (3) grazing in late spring and fall, (4) grazing in early spring, late spring, and fall, and (5) grazing in fall only.

At site 1, early spring grazing was conducted from March 9 to 16, 2003, and midspring grazing was conducted from May 2 to 17, 2003. This site was burned by wildfire in the summer of 2003, so only spring and summer data are presented for the first year. At site 2, early spring grazing was conducted from March 14 to 21, 2004. Midspring grazing was conducted from April 22 to 30, and fall grazing was conducted from October 30 to November 2. Because second-year evaluations from both site 1 and site 2 indicated that midspring grazing was the most effective treatment, an additional midspring grazing was applied from April 26 to May 2, 2005, only on treatments that included midspring grazing in 2004. In each year, the midspring grazing was timed when most medusahead plants were at the stage of stem elongation, just prior to seedhead emergence. Before plots were grazed, an adjacent area was grazed to determine appropriate stocking rates.

Sheep were contained with portable electric fencing. At each grazing time, plots were grazed concurrently at high densities (5 or 10 animals/plot) for a short duration (1 to 2 d), to remove ~50% of above-ground fresh biomass (early spring) or ~75% of biomass (midspring). These removal rates corresponded to stocking rates of 3.3 to 6.7 animal unit months/ha. This strategy was consistent with normal intensive grazing practices for grasslands. Early spring grazing took place at medusahead tillering and before the main flowering period for most species; midspring grazing took place at peak flowering for most species and when medusahead was just beginning anthesis. The fall grazing was included to reduce medusahead thatch.

Plots were evaluated in spring during peak bloom, just prior to the midspring grazing, and again in summer at peak medusahead standing cover. Medusahead cover was measured before and after grazing, and also at peak maturity (June), when it had reached its maximum cover. During the peak bloom evaluation, percent cover of all plant species, thatch, and bare ground was visually estimated in 1-m^2 quadrats (five subsamples per plot) in each year of grazing and in the year following grazing. Quadrats were tossed into each corner and into the center of each plot. MANOVA was used to compare treatment effects, with spring cover of all species plus thatch and bare ground used as dependent variables. Cover values were grouped into classes by cover type or species functional group (e.g., bare ground, thatch, medusahead, other grasses, forbs) and summed for each class, and treatments were compared using ANOVA for each cover class. Means were separated using the Student-Newman-Keuls test ($\alpha = 0.05$).

Plant diversity was calculated using Shannon's index ($H' = -\Sigma(p^*\ln p)$), where p was the proportion of each species based on spring cover data. Diversity was analyzed as a function of year and treatment with a mixed model to account for the repeated measures (H' = block + plot within block + grazing treatment + year + year·grazing treatment). Block and plot within block were random effects and the rest were fixed effects. A Box–Cox transformation ($y = [H'^{1.8} - 1]/2.66$) was applied to H' to achieve normality and homogeneity of variance of residuals.

Results and Discussion

Control of medusahead. Grazing in midspring, when medusahead was at the stem elongation stage, was very effective in reducing medusahead cover. Grazing treatments without a short intense grazing event in late spring did not control this weed. Including an earlier grazing in early spring did not increase the effectiveness of the late spring grazing.

Although cover of medusahead in ungrazed plots in June 2003 (site 1) was 38% higher than in ungrazed plots in June 2004 (site 2), the effect of the different sheep grazing regimes in the first year at both sites was remarkably similar (Figures 1a and 1b). Early spring (March) grazing significantly reduced summer medusahead cover by 24 and 37% in sites 1 and 2, respectively. By comparison, midspring (April/May) grazing reduced medusahead cover by 86 to 100%, regardless of whether it was used in combination with early spring grazing.

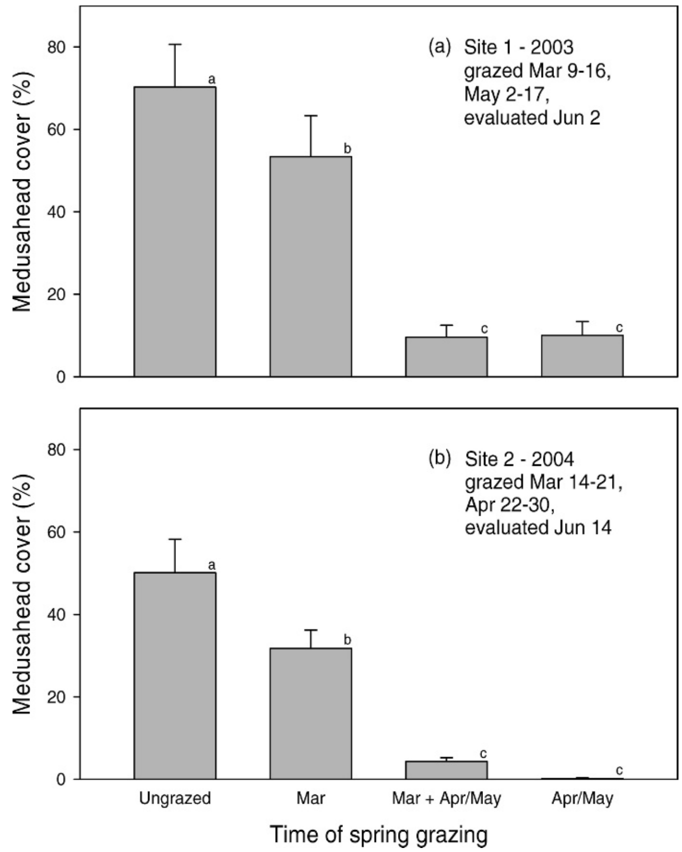

Figure 1. Medusahead at peak cover in June following first year grazing treatments for (a) site 1 (2003) and (b) site 2 (2004). Bars represent mean values + SE. Values followed by the same letter are not different (Student–Newman–Keuls test, $\alpha = 0.05$).

Fall grazing was conducted in all plots except in the ungrazed controls at site 2 in October/November 2004. In the following year (2005), the midspring grazing plots were again grazed at the same timing. Fall grazing had no impact on medusahead cover (Figure 2a). In addition, the early spring (March) grazed plots of the year before had completely recovered by the second year. When the midspring (April/May) grazed plots were grazed a second year, they again exhibited a significant reduction (88 to 91%) in medusahead cover compared to the ungrazed plots. No further grazing occurred in any plots. Peak medusahead cover was measured a year later in June 2006 (Figure 2b). Although the midspring grazing plots showed consistently lower levels of medusahead, this was no longer significantly different from the other treatments.

Interestingly, over the duration of the experiment in site 2 (2004 to 2006), the level of medusahead infestation in the ungrazed plots ranged from 50% in 2004, to 29% in 2005, and finally to 12% in 2006. It is speculated that year-to-year

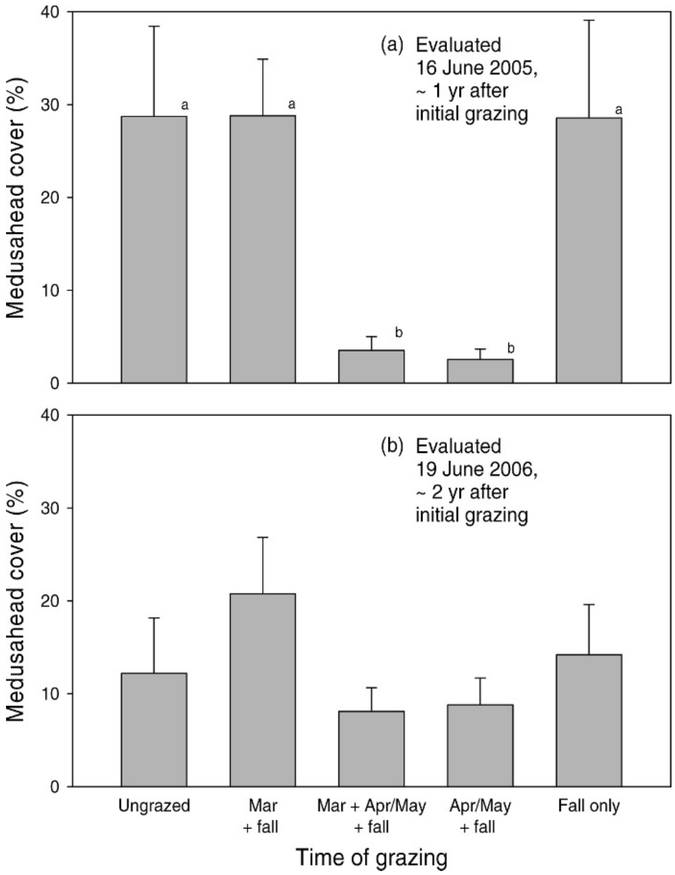

Figure 2. Medusahead at peak cover in June, (a) 1 and (b) 2 yr after the initiation of grazing in site 2. Bars represent mean values + SE. Values followed by the same letter are not different (Student–Newman–Keuls test, $\alpha = 0.05$). No statistical differences were found among treatments 2 yr after initiation of grazing.

changes in medusahead cover may be due both to variations in precipitation (i.e., higher rainfall in 2005 and 2006 may have favored competing species), and to a buildup of medusahead thatch that, over time, suppressed its own establishment.

Lusk et al. (1961) reported that while sheep will eat medusahead at all vegetative stages prior to the formation of seedheads, they avoid medusahead when the inflorescences are fully expanded and the awns are present. Although they did not provide quantitative data for control, the authors found that heavy grazing with sheep thinned medusahead infestations, but only when grazing was conducted at the boot stage in early May. This is in agreement with the results presented here for both sites 1 and 2.

In summary, late spring grazing was an effective method to control medusahead. Early spring grazing provided little control of medusahead, and resulted in only a transient reduction in thatch and increase in plant diversity. At this stage, medusahead plants were able to recover to form new seed heads.

Grazing effects on plant diversity. MANOVA using spring cover of all species plus thatch and bare ground showed highly significant treatment effects for both 2005 and 2006 ($P < 0.0001$, Wilks' lambda). A midspring (April/May) grazing during the "boot" stage of medusahead, after the elongation of internodes and before the spikes or flower heads are fully exposed, not only reduced populations of medusahead the following spring, but also increased forb cover, native species richness, and plant diversity. At this later grazing timing, it is speculated that grazed plants were unable to recover and produce new inflorescences before soil moisture was depleted. This would be expected to have a greater impact on reducing the soil seedbank in subsequent years.

Table 1. Spring cover (peak season) 1 and 2 yr after initial grazing. Within each evaluation time and cover category, values followed by the same letter are not different (Student–Newman–Keuls test, $\alpha = 0.05$). Columns lacking letters showed no significant differences among treatments within that year.

	Percent cover				
Time of evaluation/grazing treatment	Bare	Thatch	Medusahead	Other grasses	Forbs
19 Apr 2005					
Ungrazed	4.8 c	20.3 a	12.0 a	39.3 a	18.2 d
March + fall	9.8 bc	4.5 c	5.9 ab	32.6 a	44.8 b
March + April/May + fall	15.4 a	1.3 c	2.2 b	15.3 b	61.8 a
April/May + fall	12.5 ab	3.0 c	0.4 b	27.4 a	53.6 ab
Fall only	8.1 bc	15.0 b	6.2 ab	36.0 a	29.2 c
8 May 2006					
Ungrazed	13.8	23.8 a	6.4	43.2	12.9 b
March + fall	14.1	14.1 abc	12.0	47.4	12.5 b
March + April/May + fall	24.7	3.3 c	5.0	36.3	30.8 a
April/May + fall	18.6	7.3 bc	4.9	42.0	27.4 a
Fall only	17.1	20.1 ab	9.3	37.6	15.9 b

Changes in bare ground and thatch, as well as the response of other grasses and forbs, were also monitored in site 2 one year after the first grazing (2005) and in the following year (2006). Plots were evaluated at peak flowering for most annual grasses and forbs. After the first year of grazing, bare ground was highest in April/May grazed plots, with and without March grazing (Table 1). This did not persist into the next year. In contrast, thatch cover was statistically highest in ungrazed control plots and lowest in March and April/May grazed plots, or in some cases lowest in April/May grazed plots. These differences did persist into the second year. George et al. (1989) also reported that continuous intensive cattle grazing over a 2-yr period decreased the thatch layer and allowed existing thatch to decay.

Other early season annual grasses did not differ in response to most of the grazing regimes 1 yr after treatment, except for the combination of March plus April/May grazing, which caused a significant reduction (Table 1). In the second year (2006), which lacked any grazing, annual grass cover did not differ among any of the treatments. The 2006 recovery in annual grasses following the March and April/May grazing treatment was expected, as grazing exclusion in Mediterranean climates is widely recognized to lead rapidly to annual grass dominance and reduction in forbs (Bentley and Talbot 1951; Biswell 1956; Freckman et al. 1979; Jones and Evans 1960).

The response of forb species was more dramatic (Table 1). All April/May grazing treatments significantly increased percent forb cover. This cover increase was about three times that of the ungrazed plots in 2005 and remained at least twice as high as the ungrazed plots in 2006. Both native and non-native forb species increased in both years (data not shown). George et al. (1989) also reported an increase in forbs as medusahead decreased with cattle grazing. They postulated that this increase could be due to an opening of the site through a reduction in both medusahead and thatch cover.

Midspring grazing also had a positive impact on species richness (Figures 3a and 3b) and diversity (Figures 4a and 4b). In the first year after the grazing treatment, the April/May grazing timing, with or without a March grazing, resulted in a significant increase in total species richness compared to the ungrazed plots (Figure 3a), primarily due to an increase in native forb species. This statistical increase was maintained in the following year, again due to an increase in native forbs (Figure 3b). Similar results were obtained for species diversity (Shannon index) both 1 (Figure 4a) and 2 (Figure 4b) yr after the initial grazing. The Shannon index is a better indicator than species richness of evenness in distribution of species. The increase in both species richness and diversity is postulated to be due to the reduction in thatch and medusahead.

While fall grazing alone had a short-term effect on thatch, it did not prevent medusahead seed production and had no positive impact on plant diversity. In addition, sheep generally avoid areas where old litter is heavy (M. P. Doran, personal observation). However, used in combination with a midspring grazing timing, fall grazing could further reduce the thatch layer and increase the competitiveness of desirable vegetation the following year.

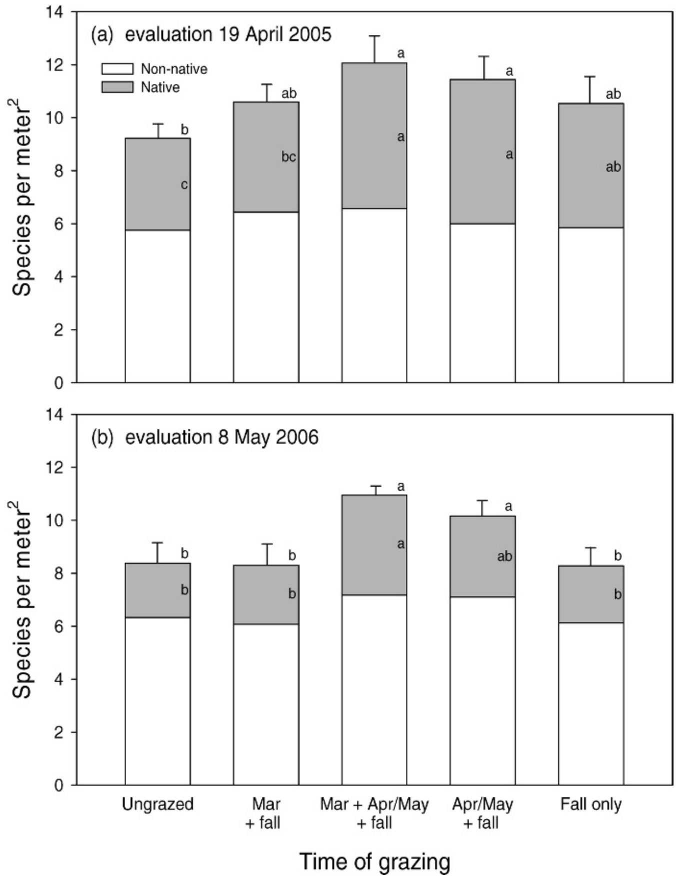

Figure 3. Species richness for native and nonnative species during peak season of flowering, (a) 1 and (b) 2 yr after the initiation of grazing in site 2. Bars represent mean values + SE for total species richness. Values followed by the same letter are not different (Student–Newman–Keuls test, $\alpha = 0.05$). Letters on top of bars represent comparison of total species richness; letters within bars represent differences in native plant species richness.

The grazing system used in this study requires high animal densities for short periods at a precise time. In such circumstances, livestock feed less selectively. High animal densities increase the grazing pressure on medusahead while avoiding detrimental impacts on more desirable species, which can occur with selective feeding behavior. High-intensity grazing did not cause detectable persistent effects on the productivity of the grassland. The herbage mass index in all treatments (unpublished data) was almost identical one and two years after grazing had been applied.

Despite the success of this study in managing medusahead, there are some logistical obstacles to this "precision" grazing approach. The window of grazing opportunity (April to

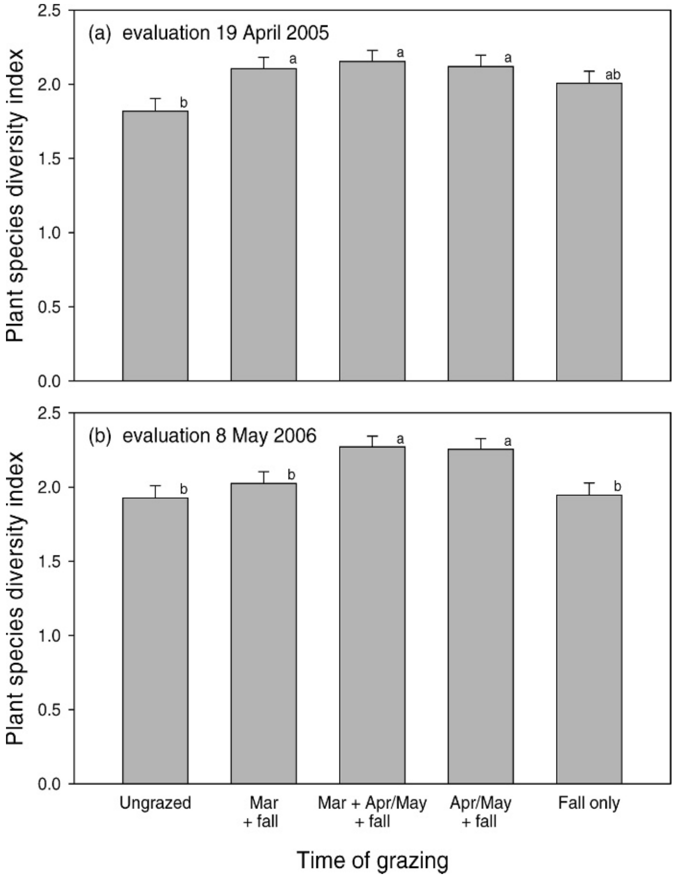

Figure 4. Shannon diversity index for all species during peak season of flowering, (a) 1 and (b) 2 yr after the initiation of grazing in site 2. Bars represent mean values + SE. Values in the figure are not transformed. Values followed by the same letter are not different (Student–Newman–Keuls test, $\alpha = 0.05$).

May) may be too narrow for high intensity grazing to be applied over large infested areas. In addition, stocking rates high enough to achieve effective medusahead control may not be feasible on a large scale due to lack of animals. However, it may be possible to work within these constraints. For example, a 100-ha ranch grazed year-round with constant stocking can support 15 to 30 sheep (0.15 to 0.30 AU/ha), depending on local forage productivity. These animals could be used to apply precision grazing on approximately 2 to 5 ha so feasibly could be used to control medusahead in different patches each year. In cases where medusahead control is of high value, custom grazing with hired animals can overcome the limitation of animal availability. Moreover, although not yet evaluated, it may be possible to achieve control at lower stocking rates, e.g., by extending the grazing period.

Precision grazing of medusahead might also be limited if high stocking densities have a negative impact on individual animal performance. However, animals with low nutritional demands, such as wethers and dry ewes, would be unlikely to sustain lasting negative impacts from short periods at high stocking rates.

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