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Medusahead is one of the most problematic rangeland weeds in the western United States. In previous studies, prescribed burning has been used successfully to control medusahead in some situations, but burning has failed in other circumstances. In this study, trials were conducted using the same protocol at four locations in central to northern California to evaluate plant community response to two consecutive years of summer burning and to determine the conditions resulting in successful medusahead control. During 2002 through 2003 large-scale experiments were established at two low-elevation, warm-winter sites (Fresno and Yolo counties) and two higher elevation, cool-winter sites (Siskiyou and Modoc counties). Plant species cover was estimated using point-intercept transects, and biomass samples were taken in each plot. After 2 yr of burning, medusahead cover was reduced by 99, 96, and 93% for Fresno, Yolo, and Siskiyou counties, respectively, compared to unburned control plots. Other annual grasses were also reduced, but less severely, and broadleaf species increased at all three sites. In contrast, 2 yr of burning resulted in a 55% increase in medusahead at the coolest winter site in Modoc County. In the second season after the final burn, medusahead cover remained low in burned plots at Fresno and Yolo counties (1 and 12% of cover in unburned controls, respectively), but at the Siskiyou site medusahead recovered to 45% relative to untreated controls. The success of prescribed burning was correlated with biomass of annual grasses, excluding medusahead, preceding a burn treatment. It is hypothesized that greater production of combustible forage resulted in increased fire intensity and greater seed mortality in exposed inflorescences. These results demonstrate that burning can be an effective control strategy for medusahead in low elevation, warm-winter areas characterized by high annual grass biomass production, but may not be successful in semiarid cool winter areas.

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

Key words: Rangeland, grassland, California, fire, invasive, prescribed burning.

Medusahead (*Taeniatherum caput-medusae* (L.) Nevski) is a late-season winter annual Mediterranean grass that infests nearly 1 million ha (~2.4 million acres) in the western United States (Duncan et al. 2004; Rice 2005). It is among the most problematic invasive annual grasses, primarily due to its opportunistic late-season phenology, long awns, poor palatability (George 1992; Lusk et al. 1961), and most importantly, its tendency to transform ecosystems by developing a persistent, silica-rich thatch (Young 1992). Although medusahead is adapted to germinating and establishing through its own thatch, the survival of other competing species is typically restricted in the presence of a thick medusahead litter layer (Evans and Young 1970; Harris 1977; Young et al. 1971).

Selective control of medusahead in rangelands and grasslands has proven difficult. For example, herbicides that control medusahead can also severely impact other desirable vegetation, particularly other annual grasses (Kyser et al. 2007; Shinn and Thill 2004). Rangeland trials with imazapic demonstrated good medusahead control and excellent control of many invasive *Bromus* species both pre- and postemergence, but other desirable

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Interpretive Summary

During 2002 through 2003, we conducted large-scale burning experiments for medusahead control in California rangeland. Trials were established at two warm-winter sites (Fresno and Yolo counties) and two cool-winter sites (Siskiyou and Modoc counties). Plant species cover and biomass were evaluated in each plot in each year. Burns were conducted in late spring to early summer. In the year after the second year burn, medusahead cover was reduced by 99, 96, and 93% for Fresno, Yolo, and Siskiyou counties, respectively, compared to unburned control plots. In contrast, two consecutive years of prescribed burning resulted in a 55% increase in medusahead at the coolest winter site in Modoc County. In the second season after the final burn, medusahead cover remained low in burned plots at Fresno and Yolo counties (1 and 12% of cover in unburned controls, respectively), but at the cool-winter Siskiyou site medusahead recovered to 45% relative to untreated controls. The success of prescribed burning was closely correlated with the dry biomass of grasses, other than medusahead, preceding a burn treatment. It is hypothesized that greater production of combustible forage in warm-winter areas resulted in increased fire intensity and greater seed mortality in exposed inflorescences. These results demonstrate that burning can be an effective control strategy for medusahead in low elevation, warm-winter areas characterized by high biomass production, but may not be successful in semiarid cool winter areas with shorter growing seasons.

annual forage grasses, such as *Avena barbata* Pott ex Link (slender oat), *Bromus hordeaceus* L. (soft brome), and *Lolium multiflorum* Lam. (Italian ryegrass), were also very susceptible to the herbicide, as were many native perennial grasses, including the *Nassella* spp. (needlegrasses), *Melica californica* Scribn. (California melic), and *Elymus glaucus* Buckl. (blue wildrye) (Kyser et al. 2007).

Using herbicides in combination with tillage and perennial grass reseeding, Young et al. (1969) achieved partial control of medusahead. However, the ability to use such integrated approaches is site specific and not practical in many rangeland systems.

In a more recent study (DiTomaso et al. 2008), intensive sheep grazing in mid-spring gave good medusahead control. However, the requirement for high stocking rates in a narrow time window limits this approach in areas with extensive medusahead infestations.

Prescribed burning is a successful management tool for a number of late-season invasive annuals in California, including *Aegilops triuncialis* L. (barb goatgrass) (DiTomaso et al. 2001), *Centaurea solstitialis* L. (yellow starthistle) (DiTomaso et al. 1999, 2006), and *Bromus diandrus* Roth (ripgut brome) (DiTomaso et al. 2006; Kyser and DiTomaso 2002). Selective control is achieved with these species by burning when their seeds are still maturing in the seedheads, but after desirable vegetation has senesced and dropped its seed to the soil surface. In grasslands, soil surface temperatures during a burn are typically < 300 C (572 F) (DiTomaso et al. 1999), which is not high enough to cause seed mortality given normal fire durations (Sweet et al. 2008). Unsenesced seeds retained in the canopy are exposed to the higher temperatures of direct flame, causing seed mortality with a much shorter exposure time (McKell et al. 1962; Sweet et al. 2008). Like barb goatgrass, medusahead senesces late in the season (Sweet et al. 2008) and should be susceptible to late spring or summer burning. While some studies have reported successful control of medusahead using prescribed burning (Furbush 1953; Murphy and Lusk 1961), others showed that burning was unsuccessful (Young et al. 1972) or inconsistent (McKell et al. 1962).

In this study, burning trials were conducted at four rangeland locations in California with different climates, vegetation types, and productivity. It was hypothesized that low elevation grasslands with high productivity and a high proportion of annual grasses produce more combustible fuel, resulting in hotter burns and longer exposure of medusahead seed to flame. Burning in these areas should result in more successful control of medusahead compared to areas with low fuel loads.

Methods and Materials

Study Sites. Field trials were established at four rangeland locations in central to northern California: two locations at low elevations with warm winters and two locations at higher elevations with cool winters. The warm-winter sites (Fresno and Yolo counties) were established in spring 2002 in blue oak woodland (Griffin 1988). The southernmost site was on the Flemming Ranch near Millerton Lake, in the central Sierra Nevada foothills in northern Fresno County, 170 m (558 ft) elevation (36.98° N, 119.68° W). The soil is Vista-Fallbrook coarse sandy loam and the site is semiarid, with 303 mm (11.9 in) mean annual precipitation (Figure 1). The second low elevation site was on the Bobcat Ranch near Winters, in the interior northern Coast Range foothills of western Yolo County, 90 m (295 ft) elevation (38.51° N, 122.03° W). The soil is Corning gravelly loam, with 581 mm (22.9 in) mean annual precipitation. Mean temperatures from November through March at these sites are 10.1 C (50.1 F) at Fresno and 10.2 C (50.4 F) at Yolo.

Two cool-winter sites (Siskiyou and Modoc counties) were established in spring 2003, both at higher elevations in sagebrush steppe (Young et al. 1988). One site was established at the Jim Rice Ranch in Siskiyou County near Grenada, in Shasta Valley between the Klamath and Cascade ranges, at 780 m (2,559 ft) elevation (41.66° N, 122.47° W). The soil is Salisbury cobbly loam, and the site receives 504 mm (19.8 in) mean annual precipitation. The highest elevation site was on Bureau of Land Management (BLM) property in southeastern Modoc County, in the Warner Mountain foothills above the Modoc Plateau at

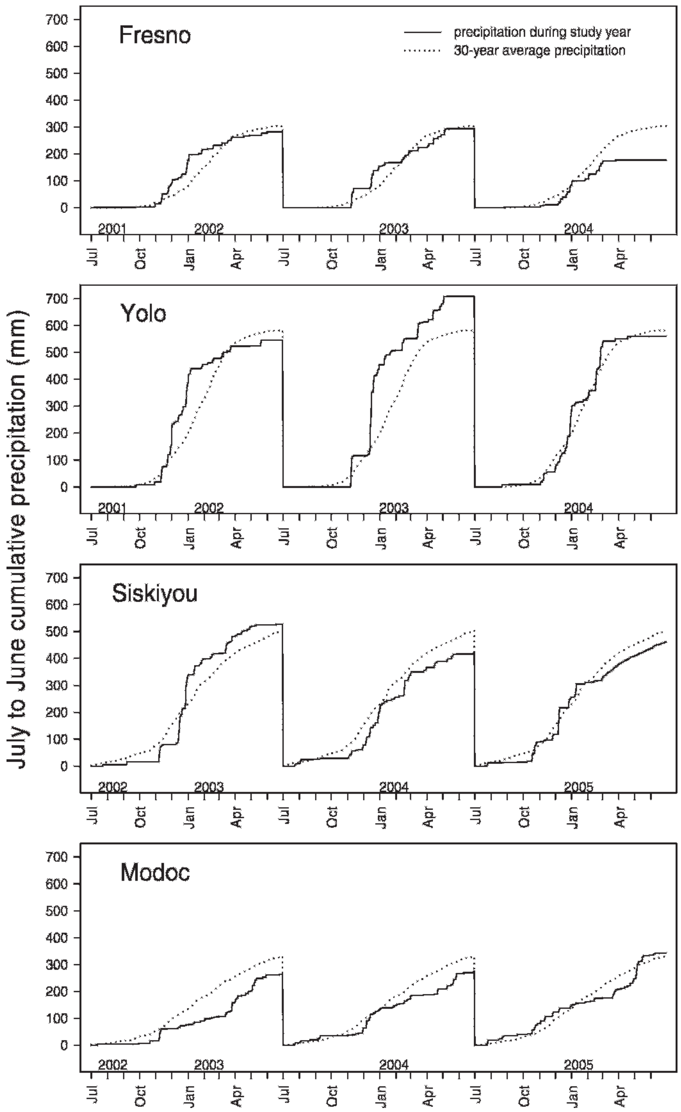

Figure 1. Precipitation at each study site over the course of the study (University of California Statewide Integrated Pest Management Program 2007). Precipitation is shown cumulatively (July 1 to June 30) with reference to the 30-yr average (dashed curve).

1,580 m (5,184 ft) elevation (41.19° N, 120.06° W). This location has Nitpac-Tunnison-Devada cobbly loam soil and is semiarid, with 332 mm (13.1 in) mean annual precipitation. Mean temperatures from November through March at these sites are 3.7 C (38.6 F) at Siskiyou and 0.3 C (32.5 F) at Modoc.

Treatments. At each site, 30 by 30-m (100 by 100-ft) plots were established, with a 3-m (10-ft) fire break around each plot. All sites were fenced to prevent grazing by livestock. Treatments were organized into randomized complete blocks with three to six replications. At all sites, treatments included burning for two consecutive summers (BB) and untreated control (C). Burns were conducted in late spring to early summer (Table 1) with the assistance of either BLM personnel (Modoc County) or California Department of Forestry and Fire Protection (Fresno, Yolo, and Siskiyou counties). All fires were initiated with a propane drip torch and burns were complete, with no unburned patches, in all plots each year and at each site.

Evaluations. Prior to burn treatments and during each year of the study, cover was estimated for all species in all plots. At the warm-winter sites (Fresno and Yolo), evaluations were taken twice per year, once in mid-spring—at peak flowering time for most species—and again in late spring/early summer (within 3 wk before burning), at peak cover for medusahead. Because the spring flowering season was more compressed at the cold-winter sites (Siskiyou and Modoc), cover evaluations were usually taken once per year during peak flowering in late spring. Cover was estimated using a point-intercept method, where each species contacting a meter stick was recorded at 30-cm (1-ft) intervals along a 15-m (50-ft) transect. Three 50-point transects were used per plot. Multiple species were often recorded at point-intercepts, and data were reported as absolute cover with total cover values often $> 100\%$. Mid-spring cover data were used to estimate species diversity (Shannon index, $H' = -\Sigma p_i \ln p_i$) (Magurran 1988). Late spring/early summer cover data taken before the burn treatment were used to estimate peak medusahead cover.

During the first evaluation of the year (mid- to late spring), three 0.25-m^2 (2.7-ft^2) quadrats were randomly tossed within each plot, and all standing biomass and thatch within the quadrats were clipped, bagged, dried for one week at 60 C, and weighed. These data were used to estimate total production (expressed as residual dry matter [RDM], kg/ha). Subsamples were combined for each plot and sent to the University of California Agriculture and Natural Resources Analytical Laboratory for forage quality analysis, including total nitrogen, protein, acid detergent fiber (ADF), and total digestible nutrients. Because there were no consistent or significant differences in forage quality between burned and control plots or between sites, the data are not presented.

Analysis. Overall significance of treatment effects was determined using multiple analysis of variance (MANOVA), with blocks and treatment as factors and with cover of all plant species as dependent variables. Cover values were arcsine square-root transformed ($p' = \arcsin\sqrt{p}$) for analysis. Treatment effects were significant ($P < 0.001$, Wilks' lambda) at all sites after both 1 and 2 yr of treatment. This analysis was followed by individual ANOVA of plant cover classes (medusahead, total of other grasses, total broadleaf forage including legumes and filaree (*Erodium* spp.), and unpalatable forbs), bare ground, summer medusahead cover, diversity, and RDM as

Table 1. Evaluation and treatment dates (month/day) within each year.

	Year 1			Year 2			Year 3		Year 4
Study site	Evaluations		Burn	Evaluations		Burn	Evaluations		Evaluation
Fresno	2002			2003			2004		2005
	4/19	5/13	5/13	4/11	6/3	6/3	4/14	5/7	6/15
Yolo	2002			2003			2004		2005
	4/9	5/23	5/31	4/21	5/29	5/29	4/23	6/14	6/16
Siskiyou	2003			2004			2005		2006
	6/18		6/20	5/19	6/22	7/9	6/7		6/15
Modoc	2003			2004			2005		2006
	6/4		6/26	6/12		7/20	6/21		6/14

dependent variables. Means were separated using the Student-Newman-Keuls test ($\alpha = 0.05$) and were back-transformed for presentation.

Results and Discussion

Vegetative Cover Responses. At the warm, low elevation sites (Fresno and Yolo counties), 1 or 2 yr of prescribed burning resulted in reduced cover of medusahead in both spring and summer, as well as reduced cover of other grasses (Table 2). In contrast, significant increases in cover of broadleaf forage species were measured at both sites following burning. Similar increases in broadleaf cover following burning, particularly legumes and filarees, have been reported in other studies (Boyd 1996; DiTomaso et al. 1999, 2001; Kyser and DiTomaso 2002; Murphy and Lusk 1961). Despite the major shifts in community composition, overall species diversity did not significantly change with 1 or 2 yr of burning.

At the Fresno County site, summer medusahead cover was $<$ 1% in burned plots, compared to 40% in unburned controls, after a single year of burning (Table 2). Even 2 yr after the second burn (2005), summer medusahead cover remained $<$ 1%. Other grasses, primarily the nonnative annuals *B. hordeaceus*, *B. diandrus*, and *Hordeum murinum* L. (wild barley), were 56% lower in burn plots after a single year of treatment (2003) and, although not statistically significant, 32% lower after 2 yr (2004). In the year following the second burn, the dominant species shifted from *B. hordeaceus* and medusahead to *Vulpia myuros* (L.) C. Gmel. (rattail fescue) and *Erodium brachycarpum* (Godr.) Thell. (short-fruited filaree) (Table 3). Cover of palatable broadleaf forage species (i.e., legumes and *Erodium* spp.) increased in the years after the first and second year burn and was two to four times higher in burned plots compared to unburned controls (Table 2). Although total cover of unpalatable forbs did not change following burning, some species tended to increase, most prominently nonnative *Hypochaeris radicata* L. (common catsear) and native *Plagiobothrys* spp. (popcornflowers). Summer medusahead cover in unburned control plots in Yolo County was higher than any other study site, ranging from 63 to 77% (Table 2). After 1 and 2 yr of prescribed fire, summer medusahead cover was 15 and 4%, respectively, relative to cover in unburned controls. By the second season after the final burn (2005), medusahead cover was still diminished but had increased to 12% relative to control plots. Other grasses at Yolo County, primarily winter annuals, responded similarly to the Fresno County site, showing 49 and 22% reduction in cover compared to control plots in the season after the first and second year burn, respectively. While *B. hordeaceus* and *Hordeum marinum* Huds. (Mediterranean barley) decreased in the burned plots, other species, including *V. myuros* and particularly *A. barbata*, increased to become the dominant grasses 1 yr after the final burn (Table 3). Broadleaf forage species increased even more dramatically than at Fresno County, with 76% cover compared to 16% in controls after 1 yr of burning, and 78% cover compared to 2% in controls after a second year. As in Fresno County, *E. brachycarpum* showed the most significant increase (Table 3). Again, overall unpalatable forb cover did not show a significant change, but some species, including nonnative *Hypochaeris glabrata* L. (smooth catsear) and native *Hemizonia* spp. (tarweeds) and *Brodiaea elegans* Hoover (harvest brodiaea), increased two- to threefold compared to the unburned controls.

At Siskiyou County, prescribed burning was fairly successful in controlling medusahead. After 1 and 2 yr of burning, spring medusahead cover was 23 and 7%, respectively, relative to cover in unburned controls (Table 2). This reduction was not sustained, however, as cover rebounded to 45% relative to unburned plots 2 yr after the final burn. Unlike Fresno and Yolo counties, burning increased the total cover of other grasses relative to control plots, by 32% after 1 yr and almost fourfold after the second year of treatment. Other grasses were predominantly *Poa bulbosa* L. (bulbous bluegrass) and *V.*

Table 2. Vegetative cover and diversity index. Comparisons are between treatments within years in each site.[a]

Site and year	Treatment	n =	Spring medusahead (% cover)	Other grasses (% cover)	Broadleaf forage (legumes, filaree) (% cover)	Unpalatable forbs (% cover)	Shannon diversity index	Summer medusahead[b] (% cover)
Fresno								
2002	Pretreatment	24	27.1	88.7	33.2	6.8	1.56	38.7
2003	Control	6	15.4	94.0	34.8	17.6	1.64	37.7
	Burned	3	0.0*	41.4*	81.2*	20.7	1.39	0.7*
2004	Control	6	35.8	82.8	16.2	10.2	1.36	47.7
	Burned twice	3	0.0*	56.0	65.0*	16.0	1.19	0.3*
2005	Control	6	- - -	- - -	- - -	- - -	- - -	29.9
	Burned twice	3	- - -	- - -	- - -	- - -	- - -	0.2*
Yolo								
2002	Pretreatment	24	29.0	72.2	17.0	13.8	1.44	63.3
2003	Control	6	39.5	87.3	15.8	12.8	1.48	73.4
	Burned	3	0.3*	44.3*	76.3*	34.3	1.56	10.7*
2004	Control	6	55.7	60.8	1.7	3.5	1.08	65.0
	Burned twice	3	0.7*	47.7	77.7*	6.3	1.10	2.7*
2005	Control	6	- - -	- - -	- - -	- - -	- - -	76.8
	Burned twice	3	- - -	- - -	- - -	- - -	- - -	8.9*
Siskiyou								
2003	Pretreatment	24	70.8	41.5	10.5	3.1	1.05	- - -
2004	Control	6	58.1	45.6	9.3	1.8	1.12	73.5
	Burned	3	13.3*	60.0	30.3*	4.3	1.42	21.7*
2005	Control	6	85.9	12.5	12.2	7.9	0.87	- - -
	Burned twice	3	6.3*	52.7*	65.0*	5.0	1.19	- - -
2006	Control	6	44.7	- - -	- - -	- - -	- - -	- - -
	Burned twice	3	20.3*	- - -	- - -	- - -	- - -	- - -
Modoc								
2003	Pretreatment	24	58.0	5.8	- - -	0.8	0.38	- - -
2004	Control	3	61.7	3.7	- - -	2.3	0.28	- - -
	Burned	3	23.0*	3.7	- - -	16.7*	1.05*	- - -
2005	Control	3	49.5	10.9	- - -	21.8	1.31	- - -
	Burned twice	3	76.5	14.9	- - -	17.8	1.08	- - -
2006	Control	3	77.8	- - -	- - -	- - -	- - -	- - -
	Burned twice	3	79.5	- - -	- - -	- - -	- - -	- - -

[a] Burn plot values with (*) are different from corresponding untreated control (Student-Newman-Keuls test, $\alpha = 0.05$).

[b] Summer medusahead cover evaluated in warm-winter sites only, except Siskiyou in 2004.

Table 3. Dominant species (> 5% vegetative cover) at each site following second burn (third year of study); based on spring transects. Grass species are in bold.

Site	Total species	Percent vegetative cover > 20%	10–20%	5–10%
Fresno				
Control	13	***Bromus hordeaceus*** ***Taeniatherum caput-medusae***	*Erodium brachycarpum* ***Vulpia myuros***	***Bromus diandrus*** ***Hordeum murinum***
Burned	12	*Erodium brachycarpum* ***Vulpia myuros***		
Yolo				
Control	12	***Bromus hordeaceus*** ***Taeniatherum caput-medusae***	***Avena barbata***	***Hordeum marinum***
Burned	10	***Avena barbata*** *Erodium brachycarpum*	***Vulpia myuros***	***Bromus hordeaceus***
Siskiyou				
Control	11	***Taeniatherum caput-medusae***	*Erodium cicutarium*	
Burned	7	*Erodium cicutarium* ***Vulpia myuros***	***Poa bulbosa***	***Taeniatherum caput-medusae***
Modoc				
Control	7	***Taeniatherum caput-medusae***	*Sisymbrium altissimum*	***Bromus tectorum***
Burned	8	***Taeniatherum caput-medusae***	*Sisymbrium altissimum*	*Blepheripappus scaber* ***Bromus tectorum***

myuros (Table 3). *Vulpia myuros* increased following burning at all three sites where it was present. Broadleaf cover responded similarly to the two more southern study areas. Cover of unpalatable forbs was minimal in all plots and did not significantly change with burning, but broadleaf forage cover, particularly *Erodium cicutarium* (L.) L'Hér. ex Ait. (redstem filaree) (Table 3) increased by three and five times compared to control plots after 1 and 2 yr of burning, respectively (Table 2).

The effect of prescribed burning on medusahead differed dramatically at the colder Modoc County site compared to the other locations. Although medusahead cover fell to 37% of values in control plots in the first year after burning, medusahead cover was not different between control and burned plots after a second year of burning or 2 yr after the final burn treatment. At this location, few grasses other than medusahead were present, and broadleaf cover was minimal, with *Sisymbrium altissimum* L. (tumble mustard) the primary broadleaf species in both burned and unburned plots (Table 3). Diversity was lower than at other sites and changes in diversity corresponded roughly with changes in broadleaf cover.

Forage Production. Best estimates of yearly biomass production were obtained from burned plots where accumulated thatch had been eliminated. As a result, forage weights were not compared between burned plots and unburned controls.

After 1 and 2 yr of burning, forage production at Fresno and Yolo counties ranged between 1,290 and 1,750 kg/ha (1150 and 1560 lb/ac), close to the normal annual production estimated by the Natural Resources Conservation Service (NRCS) for these sites (Table 4). At Siskiyou County, production in 2004 after the first burn was higher than NRCS normal annual production but dropped 76% after the second year burn. The opposite trend occurred at Modoc County, where production was normal in the first year but increased nearly fourfold in the second year, largely owing to increased cover of medusahead. These forage responses do not reflect variations in precipitation, as 2003 to 2004 was slightly drier than average at both sites and 2004 to 2005 was close to average (Figure 1).

Factors Contributing to Medusahead Control. The results reported here for Modoc County echo findings by Young et al. (1972). In their study, also conducted in Modoc County, one, two, or three successive burns did not provide effective medusahead control. Similarly, Youtie et al. (1998) conducted summer burns for medusahead control in northcentral Oregon; following some initial reduction, medusahead and other invasive annual grasses returned to pretreatment levels within 2 yr of the burn. In contrast to these reports, several studies at lower elevations in California have demonstrated good control of medusahead with a single early summer burn (Furbush 1953; McKell et al. 1962; Pollak and Kan 1996). The results of

Table 4. Forage production in burned plots, compared with estimated potential rangeland production. Natural Resources Conservation Service (NRCS) values are from the NRCS Web Soil Survey (NRCS 2007).

Location	Production in burned plots, kg/ha		NRCS Estimated dry-weight production, (kg/ha)		
	After first year	After second year	Favorable year	Normal year	Unfavorable year
Fresno	1,420	1,290	2,146	1,507	953
Yolo	1,750	1,620	2,286	1,715	953
Siskiyou	1,030	250	762	476	286
Modoc	620	2,380	392 to 1,009 (653 mean)	252 to 784 (485 mean)	168 to 560 (336 mean)
XL Ranch, Modoc County (site of Young et al. 1972)	1,620	1,700	572 to 1,210 (826 mean)	428 to 908 (623 mean)	286 to 605 (420 mean)

our study also demonstrate inconsistency in medusahead control, which may be attributed to a number of factors.

The warm-winter sites have a long spring flowering period (March to June). At these sites, most annual species complete their life cycle early, whereas medusahead initiates anthesis toward the end of the season (G. Kyser, personal observation). After other species have senesced and dropped seed, their dried foliage provides fuel to carry a fire which can destroy the exposed seeds of medusahead still held in the canopy. In the cold-winter sites, the flowering season is compressed (May to June). As a result, most winter annual species flower at nearly the same time as medusahead, resulting in a shorter burn window and less dry fuel at the time when medusahead inflorescences are exposed. Thus, the effects of burning are less selective, having a greater impact on other species and a reduced impact on medusahead. The length of the flowering season at all sites is reflected in the number of degree-days between October and June and typical annual frost-free days (Table 5).

In addition to affecting plant phenological patterns, the short growing season in cold-winter sites results in lower average annual forage production (Table 4), particularly under a semiarid precipitation regime as at the Modoc County site. This reduces the total fuel load and results in lower intensity fires. Sweet et al. (2008) found that medusahead seed is susceptible to flame temperatures at any stage of maturation but requires 5 to 7 s of exposure to achieve 90% seed mortality. This level of exposure is best accomplished with a relatively high fuel load. Furthermore, in areas where a significant proportion of winter precipitation occurs as snow, the thatch layer from previous years' production tends to be compressed, contributing minimally to the fuel load.

Plant community composition also differed between sites. Compared to the other sites, the Modoc County plots had low and variable plant diversity (Table 2), low overall species richness, a higher proportion of perennial species, and few other dominant species besides medusahead (Table 3). In particular, other grasses at Modoc represented only about 6% absolute cover at the beginning of the study, whereas other sites had 42% (Siskiyou), 72% (Yolo), or 89% (Fresno) (Table 2). Using data from three of the four sites, a strong correlation ($R^2 = 0.80$) was found between grass RDM (other than medusahead) before burning and changes in medusahead cover the season after the burn (Figure 2). The relationship was weaker when using RDM of total grasses including medusahead ($R^2 =$

Table 5. Accumulated degree-days, October 1 to June 30, during study years. Degree-days are C, single-sine, bottom at 0, with no upper limit (University of California Statewide Integrated Pest Management Program 2007). Frost-free days are estimated annual averages (NRCS 2007).

Study site and time period	Time period	Degree-days above 0 C, mean for October through June	Expected frost-free days
Fresno	2001 through 2005	3,871	238
Yolo	2001 through 2005	4,193	265
Siskiyou	2002 through 2006	2,365	125
Modoc	2002 through 2006	1,992	90
XL Ranch (Young et al. 1972)	1967 through 1971	1,791	75

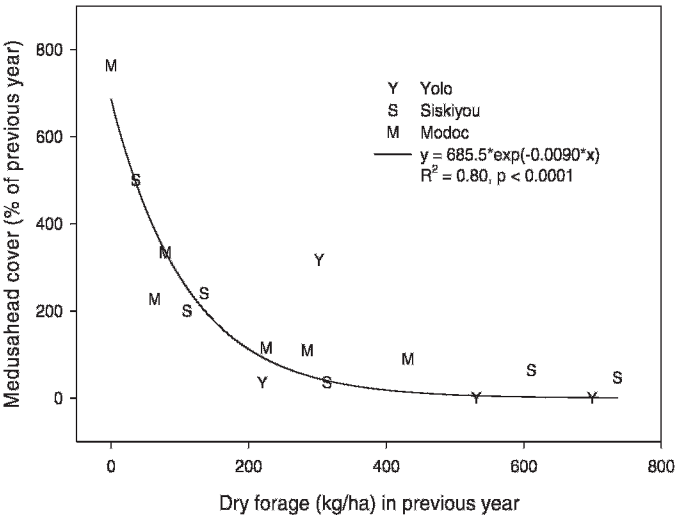

Figure 2. Relationship between dry grass forage weight preceding a burn treatment and reduction in medusahead cover in the following summer. Dry forage weight is relative cover of other grasses (omitting medusahead) multiplied by total residual dry matter (RDM). Points represent means for individual plots at each site. Data for the first year after burning is not included to avoid using thatch weight. Although Fresno data is not shown because the first-year burn resulted in nearly 100% control of medusahead, the high grass RDM and resultant control at Fresno lend peripheral support to the trend in this figure.

0.39) or when using total RDM including medusahead and broadleaf species (R^2 = 0.33) (data not shown). Other annual grasses may represent the best source of fuel for a successful prescribed burn, because their life cycle is complete and their residual standing material is dry by the time of burning. The poor correlation when medusahead was included in the analysis can likely be explained by its high vegetative moisture content at the time of burning (Sweet et al. 2008) and by its high silica content (George 1992), both of which reduce its effectiveness as a fuel.

At Siskiyou County, which is intermediate between Modoc and the other two warmer study sites in terms of climate, productivity, species diversity, and cover of other grasses, medusahead control demonstrated an intermediate response. While 2 consecutive yr of burning proved very successful, medusahead recovered rapidly following a third year without burning, similar to results reported by Youtie et al. (1998) in a similar climatic region in Oregon. It should be emphasized that native vegetation at Modoc and Siskiyou consisted largely of perennial species, including perennial grasses, which are green and poorly flammable during the warm season (R. Wilson, personal communication).

Finally, it is speculated that the scarcity of competing species, especially annual grasses, in Modoc and Siskiyou counties facilitated the rapid recovery in medusahead at these sites. Other annual grasses occupy a similar ecological niche to medusahead and would be expected to be competitive, in addition to providing the most effective fuel for burns. It is thought that poor control of medusahead at the Modoc site, in combination with the absence of competing species, resulted in a situation where burning increased the abundance and productivity of medusahead. At the Siskiyou site, medusahead control was initially more successful owing to the greater fuel load, but the success was short-lived due to the relative scarcity of competitors.

Results of this study explain the discrepant reports of medusahead management using prescribed fire. Results of our findings indicate that burning can be an effective control strategy for medusahead in low elevation, warm-winter areas in California (e.g., the Central Valley and its foothills), but may not be useful in semiarid cold-winter areas with low combustible biomass production and a low population of other annual grasses. Such conditions are typical of medusahead-infested sites in the intermountain regions of the western United States.

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