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Perennial Grass Establishment Integrated with Clopyralid Treatment for Yellow Starthistle Management on Annual Range[1]

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Abstract: Yellow starthistle is an aggressive annual forb that has invaded millions of hectares of California's annual range. Control efforts such as burning and herbicides have been effective for short-term management. However, recruitment from the seedbank or reinvasion of the annual grassland system results in a rapid return to yellow starthistle dominance. Establishing perennial grasses would be ideal for suppression of yellow starthistle. However, a lack of effective weed control options in California during a seeding program has limited perennial grass establishment. Clopyralid was used to control yellow starthistle annually for 1, 2, or 3 yr to provide a window of reduced competition for pubescent wheatgrass establishment. Total plant cover, yellow starthistle density, biomass, and seedhead number were quantified for 6 yr. Clopyralid treatment significantly reduced yellow starthistle and allowed pubescent wheatgrass establishment with a single treatment. Both clopyralid treatment and pubescent wheatgrass establishment significantly affected the range plant community composition. Annual grasses and forbs increased in plots only treated with clopyralid for 2 or 3 yr, whereas clopyralid-treated pubescent wheatgrass plots maintained lower annual grass and forb cover. Integrating pubescent wheatgrass seeding with clopyralid treatment provided long-term yellow starthistle suppression, whereas clopyralid treatment alone resulted in a plant community susceptible to repeated invasion. These findings support the establishment of competitive perennial grasses in annual grasslands as an important component of long-term yellow starthistle management.
Nomenclature: Clopyralid; yellow starthistle, *Centaurea solstitialis* (L.) #[3] CENSO; pubescent wheatgrass, *Thinopyrum intermedium* (Host. Barkworth and Dewey) Nevski var. 'Luna'.
Additional index words: Integrated management, revegetation.
Abbreviation: MANOVA, multivariate analysis of variance.

INTRODUCTION

California grasslands have experienced dramatic ecological changes during the past 200 yr. Several strongly interacting factors, including abiotic (limited and erratic precipitation), biotic (introduced species and changes in herbivore-use patterns), and anthropogenic factors (changes in land ownership and land-use patterns) have contributed to the current dominance of exotic Mediterranean annual grasses and forbs (Burcham 1956; Heady 1977).

One invader of recent notoriety is yellow starthistle, a member of the Asteraceae family that is native to the Mediterranean region. Gerlach (1997) reconstructed the yellow starthistle invasion across the West. He suggested the invasion was a long, two-step process beginning and initially spreading with alfalfa production during the second half of the 19th century and then subsequently spreading to rangelands. Only locally problematic for several decades, yellow starthistle acreage greatly expanded between 1958 and 1980, when infestations increased from slightly less than 0.5 million ha to more than 3.19 million ha (Maddox and Mayfield 1985). The most recent survey estimated that 1,935 out of 4,638 townships (where one township is 93 km^2) or 42% of the land area in California is infested (Pitcairn et al. 1998).

Yellow starthistle is well adapted for success in the California annual grassland type. Seeds rapidly germinate with the onset of fall rains, and plants overwinter as small rosettes. Rosettes are capable of persisting in newly disturbed open areas or within relatively dense annual grass canopies until late spring or early summer, when bolting and reproduction are initiated (Benefield et

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[3] Letters following this symbol are a WSSA-approved computer code from *Composite List of Weeds*, Revised 1989. Available only on computer disk from WSSA, 810 East 10th Street, Lawrence, KS 66044-8897.

al. 2001). Rapid root growth in the winter and spring allow yellow starthistle to establish a deep taproot, well below the rooting zone of most annual species in the grasslands (DiTomaso et al. 2002; Sheley et al. 1993). Plants bolt in late spring or early summer and form spiny flower heads that deter subsequent herbivory. Individual flower heads may produce more than 80 achenes with large plants producing several hundred flower heads (Benefield et al. 2001). The troublesome characteristics of yellow starthistle have been well described. It is toxic to horses (Cordy 1954), reduces forage availability once it reaches the spiny stage (Thomsen et al. 1993), deters human activities and wildlife habitat utilization, and may suppress rare native plants (Randall 1994).

Control techniques including mowing (Benefield et al. 1999; Thomsen et al. 1997), burning (DiTomaso et al. 1999a), herbicides (Callihan and Lass 1996; DiTomaso et al. 1999b), grazing (Thomsen et al. 1990, 1993, 1996), and biological control (Pitcairn et al. 2000; Villegas 1998; Villegas et al. 2000) have been studied. These efforts were somewhat successful, but none alone has eliminated yellow starthistle or prevented its reestablishment. Many of these control strategies, when implemented in heavily infested annual grasslands, allow for a temporary resurgence in exotic annual grasses, which are subsequently reinvaded by yellow starthistle, either from the soil seedbank or from seed introduction from nearby populations. The status of yellow starthistle management is clear: any strategies that do not completely eliminate the seedbank or reestablish competitive vegetation are likely to follow a pattern of initial short-term success and subsequent long-term failure in California's annual grasslands.

Current theories for long-term suppression of noxious weeds include reestablishing competitive species to occupy open niches in the system (Sheley et al. 1996). Revegetation with perennial grasses has been successfully used for suppressing noxious weeds such as leafy spurge (*Euphorbia esula*) (Ferrell et al. 1998) and Russian knapweed (*Acroptilon repens*) (Bottoms and Whitson 1998). However, establishing perennial grasses in California is difficult because of intense competition from resident annuals (Dyer and Rice 1999).

Herbicides such as glyphosate are often used in revegetation programs to release perennial grass seedlings from interspecific competition (Jacobs et al. 1999). However, yellow starthistle seeds may continue to germinate throughout the season, rendering the glyphosate treatment ineffective. Because picloram is not registered in California, available broadleaf herbicides in California for yellow starthistle control, such as 2,4-D, triclopyr, and dicamba, lack effective soil residual activity necessary for season-long control (DiTomaso et al. 1999b).

Clopyralid is a selective broadleaf herbicide recently registered for use in California that is very effective for yellow starthistle control. Clopyralid can provide season-long control with applications as early as December and also is very effective if applied in early spring (DiTomaso et al. 1999b). The selectivity exhibited by clopyralid and its residual activity may make it a useful tool in combination with glyphosate and seeding for establishing perennial grasses. Our objectives were to examine the effect of clopyralid in conjunction with glyphosate and perennial grass seeding on seeding success, yellow starthistle control, and plant community structure. To meet our objectives, we tested the following hypotheses: (1) perennial grass establishment in yellow starthistle–infested annual grasslands will be better by applying clopyralid in conjunction with a glyphosate application and seeding than seeding alone, (2) the establishment of a perennial grass in conjunction with clopyralid and glyphosate treatment will result in better yellow starthistle control than the herbicide treatment alone, and (3) clopyralid treatment integrated with seeding pubescent wheatgrass will alter plant community structure.

These hypotheses are critical to begin to address the issue of sustainable yellow starthistle control in California's annual grasslands.

MATERIALS AND METHODS

We selected an annual grassland site heavily infested with yellow starthistle in the Shasta Valley 6 mi southeast of Yreka, CA. The mean annual precipitation is 46 cm with 8.9 cm of precipitation between May and September (approximately 15% of the total annual precipitation). Plots were established on a relatively flat (0 to 2% slope) site with a southern aspect at an elevation of 800 m. The soil type is a Dotta gravelly loam (fine-loamy, mixed, mesic Pachic Argixerolls). The native vegetation supported in the area previously consisted of needlegrass (*Achnatherum* spp.), buck brush (*Ceonothus cuneatus*), Idaho fescue (*Festuca idahoensis*), and bluebunch wheatgrass (*Pseudoroegnaria spicata*). However, historic dryland farming practices eliminated the native species, and a low sere dominated by yellow starthistle, downy brome (*Bromus tectorum*), bulbous bluegrass (*Poa bulbosa*), redstem filaree (*Erodium cicutarium* L.), and other nonnative annual grasses and forbs has persisted for many years.

Plot size was 15 by 15 m, and the experimental design was 4 by 2 factorial arranged as a randomized complete block design with four replications per treatment. A total of eight treatments consisting of all combinations of the two main factors (herbicide treatment and perennial grass seeding) were applied. The factors were clopyralid treatment in spring for 0, 1, 2, or 3 consecutive yr with and without seeding pubescent wheatgrass. We selected 'Luna' pubescent wheatgrass for seeding based on its known seedling vigor, high productivity (Whitson and Koch 1998), and quantified competitive ability with yellow starthistle (Prather and Callihan 1991; Roche et al. 1997). Seeding preparation consisted of a broadcast application of glyphosate (0.33 kg ai/ha) to control resident annual vegetation and provide a window for perennial grass seedling emergence without intense interspecific competition. This application was made on February 26, 1997, with a tractor-mounted boom sprayer at 187 L/ha at 0.2 MPa pressure. The only plots treated with glyphosate were those plots that were subsequently seeded with pubescent wheatgrass. Similar herbicide application techniques were used for all subsequent annual clopyralid applications.

Pubescent wheatgrass was seeded with a no-till drill to a depth of 1.3 cm in 20-cm rows at a rate of 13.4 kg/ha. Seeding was done on March 6, 1997. This seeding time was chosen because previous research has shown that spring seeding is acceptable for pubescent wheatgrass in Northern California (Kay and Street 1961). In addition, this timing optimized annual grass control with glyphosate because little germination would be expected after this date.

Clopyralid applications were made on or near March 18 in 1997, 1998, and 1999. In 1997, clopyralid was applied at 0.07 kg ae/ha. However, in 1998 and 1999, the rate was raised to 0.11 kg ae/ha to be in accordance with the lowest registered rate for clopyralid in California. We initially used the 0.07–kg ae/ha rate because it has provided excellent yellow starthistle control (DiTomaso et al. 1999b). No herbicides were applied in 2000, 2001, or 2002.

The study area was grazed lightly each fall during the months of November and December. During this time, cattle primarily grazed dry standing forage from the previous spring and summer. Pubescent wheatgrass initiated regrowth with the onset of fall rains but grew very slowly throughout the winter and did not appear to be affected by the grazing. No spring or summer grazing was permitted during the first 4 yr of the experiment.

Each spring, we measured total plant cover for all species by visually assessing cover in five 1-m^2 quadrats randomly placed in each plot for a total of 20 quadrats per treatment. We timed this assessment to coincide with peak bloom of the annual grasses and forbs, which varied between May and June during the 6-yr period.

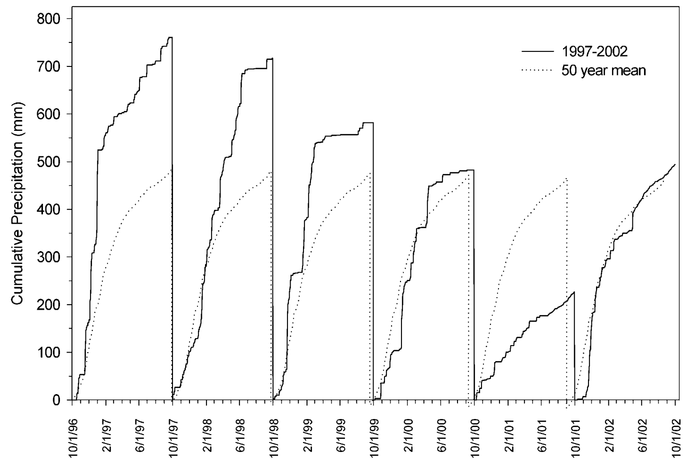

Figure 1. Cumulative annual precipitation for the period 1997 to 2002 compared with the 50-yr mean. Each annual precipitation year begins on October 1 of the previous year and ends on September 30 of the following year.

Yellow starthistle density, biomass, and seedheads produced were quantified in August each year. Three (0.25 m^2) quadrats randomly placed in each plot were clipped, harvested, and oven-dried at 65 C for 48 h.

Plant cover data were grouped into the following categories: winter annual grasses (which also included the exotic early-season perennial bulbous bluegrass), annual forbs (excluding yellow starthistle), pubescent wheatgrass, yellow starthistle, and bare ground. Because plant cover data can be highly correlated, we performed a multivariate analysis of variance (MANOVA) factorial analysis using a general linear model procedure in SAS.[4] According to MANOVA, data were analyzed with protected univariate ANOVAs for each category of plant cover data.

Yellow starthistle density, seedhead number, and biomass in late summer were highly correlated, so a MANOVA factorial analysis was performed. All three dependent variables were transformed [log(x + 1.3)] to meet the assumptions for MANOVA. According to MANOVA, each dependent variable was analyzed with protected univariate ANOVA tests.

RESULTS AND DISCUSSION

Precipitation Effects. Precipitation patterns varied greatly during the study period (Figure 1). The first 2 yr

[4] SAS, Statistical Analysis System Software, Version 6.12, SAS Institute Inc., SAS Campus Drive, Cary, NC 27513-2414.

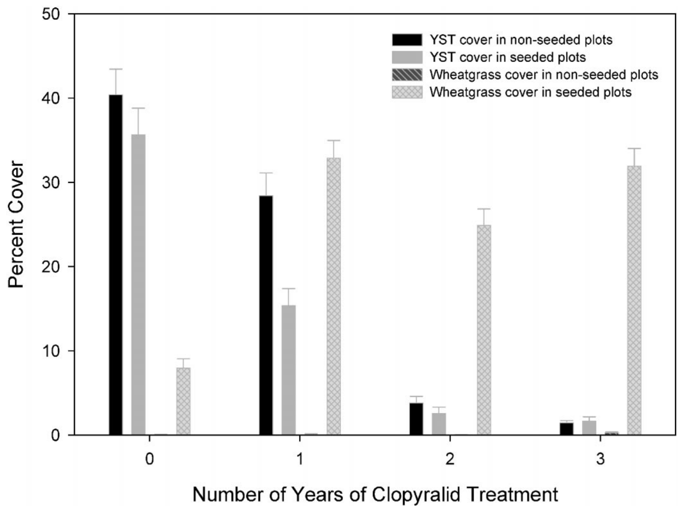

Figure 2. Spring yellow starthistle and pubescent wheatgrass cover (means ± standard error) averaged across 1997 to 2002. For yellow starthistle cover, $P_{herbicide*seeding} = 0.2614$. For pubescent wheatgrass cover, $P_{herbicide*seeding} = 0.0002$.

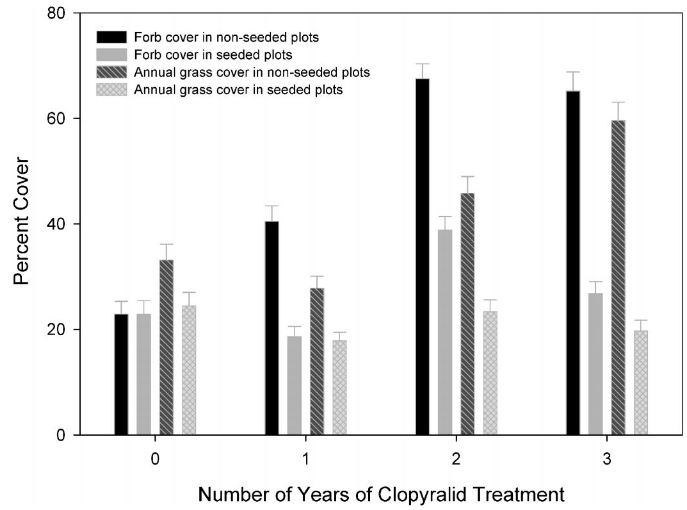

Figure 3. Spring forb cover (excluding yellow starthistle) and annual grass cover (means ± standard error) averaged across 1997 to 2002. For forb cover, $P_{herbicide*seeding} < 0.0001$. For pubescent wheatgrass cover, $P_{herbicide*seeding} < 0.0001$.

(1997 and 1998) were characterized by wet winters, with well above average precipitation throughout the spring and into early summer in 1998. The third year (1999) was characterized by above-average precipitation during the winter followed by a very dry spring and summer. The fourth year (2000) generally followed the 50-yr mean in both timing and intensity of precipitation. The fifth year (2001) was characterized by severe drought, with less than 46% of average annual precipitation, which also resulted in the complete death of all yellow starthistle plants in the study area by midsummer. The sixth year precipitation patterns very closely followed the 50-yr average in both timing and intensity. Clearly, differences in precipitation patterns among years can greatly affect annual grass and forb responses on the California annual grasslands (Pitt and Heady 1978). However, these precipitation patterns do provide an indication of pubescent wheatgrass establishment and clopyralid efficacy for yellow starthistle control over a series of very different years.

Vegetative Cover. MANOVA indicated that there were highly significant year, clopyralid treatment, and pubescent wheatgrass seeding effects on all plant cover groups. In addition, all interactions between these factors had significant effects on vegetative cover (Wilks lambda $P \leq 0.0001$ for all main effects and interactions).

Pubescent wheatgrass cover was affected by year, clopyralid treatment, seeding, and all possible interactions. Despite the year effects, we have chosen to present the data by the clopyralid treatment by seeding interaction (Figure 2). During the 6-yr period, pubescent wheatgrass cover averaged 25 to 35% in plots treated with one, two, or three annual clopyralid applications and seeded with pubescent wheatgrass, whereas untreated plots that were seeded averaged less than 10% pubescent wheatgrass cover. There appeared to be no difference in pubescent wheatgrass establishment between plots treated for 1 or 3 yr with clopyralid, which suggests that pubescent wheatgrass may only need one season of yellow starthistle control for successful establishment. Pubescent wheatgrass cover was less than 1% in unseeded plots, suggesting that its spread may be limited where surrounding competition is intense. Vegetative spread may occur through rhizomes (Hickman 1993). However, we observed very little colonization around the periphery of seeded plots into unseeded plots.

Spring cover by yellow starthistle was affected by clopyralid treatment and pubescent wheatgrass seeding; however, the treatment by seeding interaction was not significant (Figure 2). During the 6-yr period, two or three annual clopyralid treatments reduced yellow starthistle spring cover to less than 5%, with or without seeding. Seeding alone had no effect on yellow starthistle cover because pubescent wheatgrass failed to establish well without clopyralid treatment. By 2002 (3 yr after the final clopyralid treatment) yellow starthistle cover was less than 3% and not different among plots seeded and treated with clopyralid for 1, 2, or 3 yr (data not shown).

Forb cover (excluding yellow starthistle) was affected by clopyralid treatment and pubescent wheatgrass seeding (Figure 3). Forb cover nearly doubled in plots treated

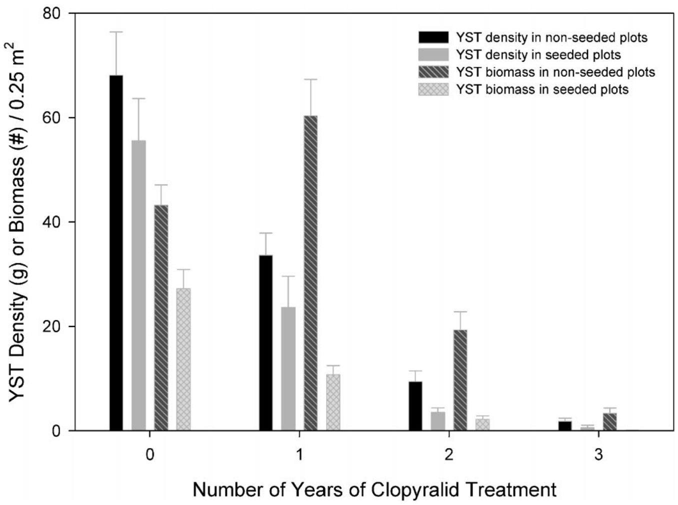

Figure 4. Late summer yellow starthistle (YST) density and biomass (means ± standard error) averaged across 1997 to 2000 and 2002. Final YST density in 2001 was zero in all plots and was excluded from the analysis. For YST density, $P_{herbicide*seeding} = 0.91$. For YST biomass, $P_{herbicide*seeding} = 0.0002$.

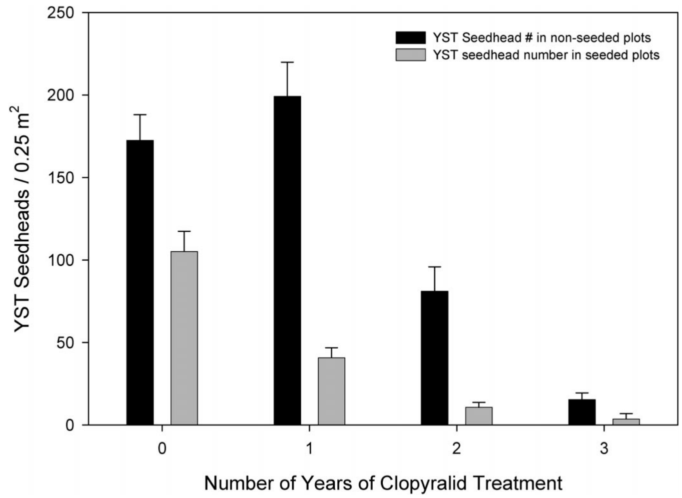

Figure 5. Late summer yellow starthistle (YST) seedhead number (means ± standard error) averaged across 1997 to 2000 and 2002. Final YST seedhead number in 2001 was zero in all plots and was excluded from the analysis. For YST density, $P_{herbicide*seeding} = 0.0005$.

with clopyralid for 1, 2, or 3 yr compared with plots treated and seeded. The primary forbs that strongly increased in the treated plots included redstem filaree, tumble mustard (*Sisymbrium altissimum* L.), and coast fiddleneck (*Amsinckia intermedia* Fisch. & Mey.). It is significant to note that none of these species are controlled by clopyralid and were released when competition with yellow starthistle was removed. Forb cover in plots seeded and treated for 1 or 3 yr was generally similar to the untreated control. Pubescent wheatgrass also appears to suppress many other annual forbs along with yellow starthistle.

Annual grass cover (including the early-season perennial bulbous bluegrass) was affected by clopyralid treatment and pubescent wheatgrass seeding in a manner similar to forb cover (Figure 3). Increases in annual grass cover occurred in plots treated with clopyralid for 1, 2, or 3 yr, with the greatest increases seen in plots treated for 2 or 3 yr. The primary species that increased included downy brome, wild barley (*Hordeum* spp.), common rye (*Secale cereale*), and bulbous bluegrass. Annual grass cover was very similar among plots treated and seeded compared with the untreated control. The data show that pubescent wheatgrass is capable of suppressing many annual grasses.

Yellow Starthistle Density, Biomass, and Seedhead Production. Years of clopyralid treatment interacted with seeding to highly influence yellow starthistle biomass ($P = 0.0002$) but not yellow starthistle density ($P = 0.91$) (Figure 4). Across 6 yr, yellow starthistle density averaged 68 plants/0.25 m^2 in the untreated control compared with 56 plants in plots only seeded. Increasing the number of clopyralid treatments decreased starthistle density to less than 2 plants/0.25 m^2 in plots treated for 3 yr (97% reduction). However, there were no differences between plots treated for 1, 2, or 3 yr and those treated for 1, 2, or 3 yr and seeded, respectively. Across 6 yr, yellow starthistle biomass average 43 g/0.25 m^2 in the untreated control compared with 27 g in plots only seeded. The most dramatic difference in biomass (82% reduction) was evident between plots only treated for 1 yr (60 g/0.25 m^2) and plots treated for 1 yr and seeded (10.7 g/0.25 m^2). Treatment for 2 or 3 yr with seeding resulted in the greatest biomass reductions (<3 g/0.25 m^2).

Yellow starthistle seedhead numbers paralleled the effect on yellow starthistle biomass. The treatment by seeding interaction was highly significant for seedhead numbers ($P = 0.0005$). During the 6-yr period, yellow starthistle averaged 172 seedheads/0.25 m^2 in the control compared with 105 seedheads/0.25 m^2 in plots only seeded (Figure 5). Again, the most dramatic difference (79% reduction) occurred between plots treated for 1 yr (199 seedheads/0.25 m^2) and plots treated for 1 yr and seeded (41 seedheads/0.25 m^2).

The data collected for 6 yr provide quantitative answers to the hypotheses tested concerning the role of clopyralid and glyphosate treatments for yellow starthistle control and perennial grass establishment in annual grasslands. Our data support our first hypothesis that perennial grass establishment in yellow starthistle–infested annual grasslands will be better with the application clopyralid in conjunction with a glyphosate application and seeding than seeding alone. Even a single initial clopyralid application significantly increased pubescent wheatgrass establishment. The need to release pubescent wheatgrass seedlings from yellow starthistle competition was very evident in the year of seeding. However, once pubescent wheatgrass seedlings survived the first year, additional applications of clopyralid did not improve their establishment.

We observed that pubescent wheatgrass establishment was very limited when seeding occurred without clopyralid treatment. These plots exhibited very poor stands during the 6-yr period with slightly less than 10% cover. It is possible that long-term pubescent wheatgrass recruitment may occur in these plots. The rhizomatous nature of perennial grass species such as pubescent wheatgrass may improve stand establishment over time, whereas recruitment from seeds may frequently fail within annual grasslands (Fossum 1990).

Our second hypothesis, that the establishment of a perennial grass in conjunction with clopyralid and glyphosate treatment will result in better yellow starthistle control than the herbicide treatment alone also was supported by the data. During the course of the study, yellow starthistle density, seedhead number, and biomass were decreased after clopyralid treatment and pubescent wheatgrass seeding. Yellow starthistle germinated and survived in between pubescent clumps, but establishment of the perennial grass decreased growth and fecundity of yellow starthistle. During the course of the study, the most striking difference was observed between plots seeded with pubescent wheatgrass and treated with clopyralid for 1 or 2 yr and plots only treated with clopyralid for 1 or 2 yr. The former exhibited dramatic declines in yellow starthistle biomass and seedhead production, whereas the latter rapidly reverted to the condition of the untreated control. Using clopyralid to control yellow starthistle and allow pubescent wheatgrass establishment resulted in better yellow starthistle suppression in the study period after the last clopyralid treatment.

Roche et al. (1997) determined two factors that substantially reduce yellow starthistle invasion into seeded perennial grass stands in Washington: shading during winter and spring and depletion of soil moisture in late spring and summer. They additionally concluded that pubescent wheatgrass was highly effective in suppressing yellow starthistle. However, the study design to determine this used a seeding row spacing of 4.7 cm, and no seeding rate information was provided. Based on the row spacing, unrealistic seeding rates would have likely been used. High seeding rates have been studied as a strategy for increasing the competitive ability of intermediate wheatgrass in relation to spotted knapweed (*Centaurea maculosa*) (Velagala et al. 1997). However, this strategy is economically difficult to justify and has not been well tested beyond small-plot studies.

Borman et al. (1991) demonstrated the importance of fall and winter perennial grass growth for suppression of annual weeds. In their study, orchardgrass (*Dactylis glomerata*), which initiated growth in the fall and grew during winter, better suppressed yellow starthistle than intermediate wheatgrass, which did not begin to grow until spring. However, their study was only conducted during a 2-yr period, and intermediate wheatgrass may not have been fully established. Vegetative cover results from our study indicated pubescent wheatgrass, which is taxonomically very similar to intermediate wheatgrass (Dewey 1978; Mariam and Ross 1972), required 3 yr to fully establish. However, suppression of yellow starthistle biomass and seedhead production occurred before full establishment. We observed that pubescent wheatgrass initiated fall growth but grew very little during the winter months. Although no light measurements were taken, light intensity would not have likely differed between pubescent wheatgrass seeded and unseeded plots based on the presence of pubescent wheatgrass cover. Our plots also were subject to light grazing from November through December each year, which would serve to potentially reduce pubescent wheatgrass cover during that time. Understanding the way seasonal grazing affects this competitive interaction between yellow starthistle and perennial grasses will be crucial for rangeland managers that desire to establish perennial grasses as their forage base.

Our data also supported our third hypothesis that clopyralid treatment integrated with seeding pubescent wheatgrass will alter plant community structure. Although annual grass cover varied among years, there were notable trends in the response to clopyralid and wheatgrass. Mostly exotic annual grasses, including the perennial bulbous bluegrass [primarily downy brome, common rye, and hare barley (*Hordeum murinum*)], generally increased when repeated annual clopyralid treatments were applied compared with the nonsprayed control treatment. This response suggests an indirect response of annual grasses being released from competition when yellow starthistle is controlled. When pubescent wheatgrass was seeded, there also was evidence for suppression of annual grasses. Pubescent wheatgrass has effectively suppressed downy brome in studies conducted in Wyoming (Whitson and Koch 1998).

Total forb cover generally responded positively to clopyralid treatment. The primary forbs that positively responded to clopyralid application were redstem filaree, tumble mustard, and *Amsinckia menzesii* var. *intermedia*. None of these species are of the plant families clopyralid is known to be highly active on (Asteraceae, Fabaceae, Polygonaceae, Solanaceae, and Apiaceae). There were few species at our study site from these susceptible families, and overall forb response would likely have been negative if a larger component of the forbs had been from these susceptible families. Therefore, the advantage of clopyralid selectivity among broadleaf species may only be found where the majority of the desirable forbs are not in these families. This advantage may be lost in many areas of California grasslands, where the Asteraceae and Fabaceae families contribute a great number of species to the forb component. However, the short-term negative effects need to be examined in regard to the long-term effects of continued yellow starthistle dominance. After pubescent wheatgrass successfully established, forb suppression was apparent during the course of the study. Plots with pubescent wheatgrass had significantly lower forb cover than plots without wheatgrass. Long-term effects of pubescent wheatgrass establishment on forb populations are uncertain, although it appears that pubescent wheatgrass may suppress many forbs. It has been used to suppress highly competitive noxious forbs such as leafy spurge (Ferrell et al. 1998) and Russian knapweed (Bottoms and Whitson 1998). Further studies should be conducted in wildland areas where objectives are directed at managing for a diverse mix of native forbs.

In summary, clopyralid effectively controlled yellow starthistle, which allowed pubescent wheatgrass to establish. Increasing the number of clopyralid treatments beyond one treatment did not improve pubescent wheatgrass establishment. After the final herbicide application, pubescent wheatgrass continued to suppress yellow starthistle growth and reproduction. These results strongly support the integration of competitive vegetation for long-term yellow starthistle management and the role of integrated strategies to that end.

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