Restoration Ecology
THE JOURNAL OF THE SOCIETY FOR ECOLOGICAL RESTORATION INTERNATIONAL

# Restoration of California Native Grasses and Clovers: The Roles of Clipping, Broadleaf Herbicide, and Native Grass Density

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## Abstract

**One of the major challenges confronting grassland restoration of highly invaded communities is increasing the diversity of native species. There is surprisingly little research investigating how reconstructed native grasslands respond to common management techniques and how these techniques influence the relative establishment of both native grasses and forbs. Despite the diversity and wide distribution of native clovers in California, few practitioners incorporate them into grassland restoration plans. Conversely, non-native clovers have been seeded extensively onto California rangelands. This study addresses the following questions: (1) Using readily available management tools, is there a strategy that can benefit the growth of both planted native bunchgrasses and seeded clovers? (2) Do native bunchgrasses compete with establishing clovers and non-native grasses? (3) Do native and non-native clovers differ in their response to management treatments or in their productivity? Plots were established to test three factors in different combinations over 3 years: (1) early spring clipping, (2) initial broadleaf herbicide, and (3) native bunchgrass planting density. Native and non-native clovers were seeded in years 2 and 3. Early spring clipping did not have a significant effect on native bunchgrass cover, yet it did result in greater growth of native and non-native clovers. The direction of the response to broadleaf herbicide changed between years for native bunchgrasses and was consistently negative for native clovers. Plots with higher native grass densities did not adversely affect the seeded clovers, yet non-native grass cover was reduced. Native and non-native clovers exhibited similar responses to clipping and established at similar densities.**

**Key words: 2,4-D, California grassland, clipping, clovers, grassland restoration, *Nassella pulchra*.**

## Introduction

Although the current extent of California grasslands is similar to that which occurred prior to European colonization (pre-European: 9.2 million ha, post-European: 8.98 million ha; Barbour & Major 1990; Schoenherr 1992), there are fewer than 2% of intact native grasslands remaining (Noss et al. 1995). This change has come about as a result of both the creation of grasslands from former wetland or shrubland communities and the destruction of pristine grasslands through current and historic agricultural practices, development, and invasion by non-native annual grasses (Burcham 1957; Barbour & Major 1990; Heady et al. 1992).

Like other grassland communities, disturbance regimes are an important force in structuring California grasslands. The role of specific disturbances on native species in a pristine community may be very different from their role in grasslands now dominated by non-native annual grasses. For example, several studies have found that excessive foliage removal of native perennial bunchgrasses, especially during the late spring when they are in flower and soil moisture is low, is detrimental to their growth and survival (Sampson & McCarty 1930; Love 1944; Huntsinger et al. 1996; Kimball & Schiffman 2003; Bartolome et al. 2004). In contrast, clipping or grazing may indirectly benefit native bunchgrasses when they are among faster growing non-native annual grasses, particularly when they are young (Stromberg & Kephart 1996; Brown & Rice 2001). Determining an appropriate management regime for this system, therefore, becomes complicated when trying not only to consider responses from the native community but also to determine how native groups may differentially respond to management regimes while interacting with non-native annual grasses.

The majority of studies investigating the influence of disturbances (i.e., grazing, clipping, or fire) on native-dominated grasslands in California have been conducted on existing populations of native species (Dyer et al. 1996; Huntsinger et al. 1996; Hatch et al. 1999; Meyer & Schiffman 1999; Dyer 2003; Hayes & Holl 2003*a*, 2003*b*; Kimball & Schiffman 2003; Marty et al. 2003; Bartolome et al. 2004; but see Love 1944). Most grassland restoration

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doi: 10.1111/j.1526-100X.2007.00334.x

projects, however, are initiated under disturbed conditions with few or no established native species. The role of disturbance in establishing native communities may be different from its role in maintaining remnant communities with a shared history of ecological interactions.

One of the major challenges to restoring grassland diversity is identifying an appropriate management strategy or disturbance regime that fosters management goals for some species while at the same time not inhibiting goals for others. Restoration projects and research on grasslands in lowland Britain (Pywell et al. 2003) and the Great Plains (Zajicek et al. 1986; Piper & Pimm 2002) suggest that one of the major challenges to restoration of species richness is management of native forbs, whereas establishment of native perennial grasses is less challenging, particularly given time for ecological succession. In California grasslands, the process of successfully establishing native grass seedlings in a neighborhood of non-native annual grasses is difficult, requiring management intervention and further research (Menke 1989; Amme 1992; Heady et al. 1992; Anderson & Anderson 1996; Dyer & Rice 1999; Brown & Rice 2000; Dyer 2003). Perhaps because of this challenge, there is a dearth of restoration projects and research that includes both native grasses and forbs (but see Love 1944; Meyer & Schiffman 1999; Hayes & Holl 2003*a*).

California grassland forbs comprise virtually the entire annual component and the majority of the species richness of the native grassland community. In California, studies investigating the relative compatibility of native versus non-native grasses with native forbs are few, and the results are mixed (Carlsen et al. 2000; Brown & Bugg 2001). In the Great Plains, perennial grasses generally outcompete grassland forbs in the absence of disturbance (Zajicek et al. 1986).

In addition to non-native annual grasses, interference from broadleaf weeds can pose a significant threat to native grass plantings in California (DiTomaso 2000). Because broadleaf herbicide can be applied after native bunchgrasses have been planted, restoration practitioners sometimes delay seeding native forbs until after chemical control of broadleaf weeds has been conducted. Filaree (*Erodium botrys*) is a common non-native forb in northern California annual grasslands and often proliferates after burning or clipping (Megan Lulow 2000, Irvine Ranch Conservancy, personal observation). Native bunchgrass seedling establishment is generally negatively influenced by this species (Lulow et al. 2007), yet I know of no studies testing the effects of controlling it while establishing other native grassland groups. Herbicide application can be expensive; cost considerations, coupled with the potential forage value of *E. botrys*, may reduce the incentive for landowners to use chemical control.

The purpose of this study was to test the efficacy of specific management techniques in establishing native bunchgrass and clover populations in order to develop a "best practice" management approach for incorporating native clovers into the native grassland restoration process. The wild clovers (*Trifolium* spp.) represent a substantial and highly diverse forb group in California grasslands. Furthermore, California represents an important biogeographical region in the evolutionary radiation of native *Trifolium* species. Native *Trifolium* species are highly diverse and remain understudied, yet non-native clovers have been used extensively for range improvement in California grasslands.

I chose what I found to be the most typical approach to restoration of California native grasses and forbs and then modified specific aspects of this overall approach to test their effects. Excluding weed control practices the year prior to seeding with native grasses, the typical approach to grassland restoration is as follows: (1) the use of broadleaf herbicide in the first year to minimize interference from non-native forbs and (2) clipping in the early spring (i.e., before significant soil moisture depletion) to minimize interference from non-native annual grasses. Where attempts to incorporate native forbs into grassland restoration have been made, forbs are generally seeded in the second or third year after broadleaf herbicide application has terminated.

This study addressed the following general questions: (1) Using readily available management tools (e.g., clipping and herbicide), is there a strategy that can benefit both native grasses and clovers? (2) Do native grasses compete with establishing native clovers or non-native grasses? (3) Do native and non-native clovers differ substantially in their response to management treatments and measures of productivity?

## Methods

I conducted this study in open grassland in the eastern low foothills of the northern Coast Range near Winters, California (lat 38°38″01′N, long 122°03″05′W). The region experiences a Mediterranean climate, with a 30-year mean annual rainfall of 580 mm; most of which falls from October to April (National Weather Services Cooperative Station Network, Winters, CA, U.S.A.). Yearly precipitation over the course of the study (July through June) was 545, 708, and 560 mm in 2001–2002, 2002–2003, and 2003–2004, respectively. During the year the native grasses were planted (2002), spring precipitation was abnormally low at 17% of the 30-year average rainfall. In an attempt to compensate for this dry spell, all plots were supplemented with water in March (13 mm) and April (10 mm), but total amounts of water received were still well below the 30-year monthly average. The soil at the study site is classified as part of the Sehorn-Balcom complex (fine, montmorillonitic, thermic Entic Chromoxererts) with generally moderate-to-high natural fertility (Andrews 1990). The dominant non-native grass species during the study were *Lolium multiflorum* and *Bromus hordeaceus*. Other species present included *Vulpia myuros* and *Taeniatherum caput-medusae*.

Native clover species and non-native commercial varieties capable of growing in upland dry environments in northern California were selected based on interviews with regional botanists and commercial producers, as well as available literature (Table 1; Graves et al. 2001). Local ecotypes of native grass species known to occur in the region were selected and plug planted at different proportions based on species success and compatibility observed in previous restoration projects and research. These proportions were *Nassella pulchra* (3):*Nassella cernua* (2):*Melica californica* (2): *Elymus glaucus* (1):*Koeleria macrantha* (2). Native clover seeds were either hand collected in the region or purchased from a grower producing local seed (Hedgerow Farms, Winters, CA, U.S.A.). Native clover seeds were scarified by hand with sandpaper prior to seeding to increase germination rates. Unscarified non-native clover seeds coated with *Rhizobium* inoculum were purchased from a local grower (TS and L Seed, Woodland, CA, U.S.A.). Germination trials in moist soil were conducted for all clover species prior to seeding in order to calculate comparable seeding rates among species. Based on these trials, seed amounts were adjusted to approximately 376 germinable seeds/m$^2$ (35 seeds/ft$^2$) among species. Prior to broadcasting seeds, the appropriate amounts of each species were combined and mixed thoroughly with minimal amounts of bran flakes to prevent seeds from settling in bags.

In an attempt to mimic site preparation techniques common to grassland restoration in the region, a late-spring burn was conducted at the end of the 2001 growing season to reduce seed production by non-native annual grasses. In the fall of year 1 (2001), thirty-five 1.5 × 1.5–m plots were arranged as a completely randomized design with seven treatment combinations, five replicates each, and 1.5 m separation between plots. The study area was fenced with chicken wire to minimize rabbit herbivory, and electric fencing was used to exclude cattle. The study was not designed as a complete factorial, and therefore, only particular combinations of management treatments suitable to test study hypotheses were applied (Table 2). Native grasses were planted in February of year 1 using templates for equal spacing at two densities: 22 plugs/m$^2$ (21.3 cm spacing) and 48 plugs/m$^2$ (14.3 cm spacing). The clovers were sown into the plots in years 2 and 3 of the study (Table 3). Plots were seeded again with clovers in year 3 because leaf area index (LAI) values were low for clovers after the first seeding.

The broadleaf herbicide (2,4-D) treatment was applied twice in the first year prior to clover introductions (Table 3). The clipping treatment was conducted using a brush cutter and applied twice each spring to a height of

**Table 1.** Species list of planted native grasses and seeded clovers.

| *Native Grass Species* | *Native Clovers* | *Non-Native Clovers* |
|---|---|---|
| *Elymus glaucus* Buckley | *Trifolium bifidum* A. Gray | Hykon rose clover (*T. hirtum* All.) |
| *Melica californica* Scribner | *T. ciliolatum* Benth. | Monte Frio rose clover (*T. hirtum* All.) |
| *Koeleria macrantha* (Ledeb.) J. A. Shultes | *T. gracilentum* Torrey & A. Gray | Denmark subclover (*T. subterraneum* L.) |
| *Nassella pulchra* (Barkworth) | *T. willdenovii* Sprengel | Nungarin subclover (*T. subterraneum* L.) |
| *N. cernua* (Stebb. & Love) Barkworth | | |

**Table 2.** Management strategies (treatments) differing in clipping, native grass planting density, broadleaf herbicide, and seeded clovers.

| *Management Strategy (Treatments)* | *1* | *2* | *3* | *4* | *5* | *6* | *7* |
|---|---|---|---|---|---|---|---|
| Clipping | No | Yes | No | Yes | No | Yes | No |
| Native grass density | High | High | High | High | High | Low | Low |
| Broadleaf herbicide | Yes | Yes | Yes | Yes | No | Yes | Yes |
| First-year plug planting | NG | NG | NG | NG | NG | NG | NG |
| Second- and third-year seeding | NC | NC | N-NC | N-NC | NC | NC | NC |

NG, native bunchgrass; NC, native clover; N-NC, non-native clover.

**Table 3.** Dates of treatment applications.

| *Year* | *Broadleaf Herbicide* | *Native Grass Planting* | *Clover Seeding* | *Clipping (6–7 cm)* | *Clipping (10 cm)* |
|---|---|---|---|---|---|
| 1 (2001–2002) | December 11, March 5 | February 15 | | April 7 | April 29 |
| 2 (2002–2003) | | | November 16 | March 2 | March 23 |
| 3 (2003–2004) | | | November 2 | February 20 | March 16 |

6–7 cm in the first clipping and 9–10 cm in the second clipping (Table 3). During the first spring, the clipping treatment was applied later because the bunchgrasses were planted in February that year. Clipping was initiated as growth rates of non-native grasses increased and stopped prior to substantial declines in soil moisture (usually just prior to grass flowering).

Data collection occurred during the late flowering period for clovers (usually late March) and native grasses (usually late April) in years 2 and 3. In year 1, data were collected on the LAI of native and non-native grasses and *Erodium botrys* (essentially the only forb species present), but interpretation of grass data is limited because there was relatively little time prior to summer dormancy for native grasses to measurably respond to treatment effects. Measurements of LAI were obtained using a pin frame with 50–60 pins per plot for native grasses and clovers and 30 pins per plot for annual grasses because they were more prolific. In year 3, LAI measurements were obtained for grasses only. Due to low LAI values for clovers in year 2, clover densities were recorded instead in year 3 in an attempt to improve the ability to detect their response to treatment effects. Clover densities were recorded as the number of individuals in a 0.5 × 0.5–m subsample using two subsamples per plot. In addition, within 2 months of the beginning of the growing season in year 4 (30 November 2004), measurements of LAI were taken for native grasses and native clovers in selected treatments to further substantiate clipping results from the spring 2004 data collection period (year 3).

In April of year 2 only, measurements of photosynthetically active radiation (PAR) were taken using a Decagon sunfleck ceptometer (Decagon Devices Inc., Pullman, WA, USA), and the density of native grasses was recorded the following growing season in December. PAR measurements were taken to confirm that the clipping treatment was in fact increasing available light. Native grass density was recorded to obtain accurate counts of individuals for the density treatment due to some mortality. Three PAR measurements were taken in each plot by inserting the meter across the plot, both above the canopy and at the ground level, in three evenly spaced locations. Bunchgrass densities were measured by counting the number of individuals within 0.25 × 0.25–m subplots using three subplots per plot.

Unless results varied from the second year of the study (2003), discussion of data analyses in the Results and Discussion sections focuses on the third and final year of the study (2004).

### Statistics

Differences among all seven management treatments were tested using single-factor analyses of variance (ANOVAs) for the different dependent variables. When necessary, variables were natural log or square root transformed to satisfy the parametric assumptions of analyses. Analyses were conducted using SAS statistical software (SAS Institute Inc. 2002).

To test the responses of native and non-native grasses to different management treatments, I ran a multivariate analysis of variance with both grass types as dependent variables (log transformation for non-native grasses). I used standard least squares to distinguish between the dependent variables.

To test the response of clovers to different management treatments, I used an ANOVA with clover density (square root) as the dependent variable. As mentioned above, in the early winter of year 4, measurements of LAI were collected for native grass and native clovers using plots treated with herbicide and planted at the high native grass density to compare clip and no-clip treatments. Treatments were tested with two ANOVAs, one for each of the dependent variables: native grasses (log) and native clovers. I tested for differences in litter (year 2 (log) and year 3) and PAR (year 2 (log)) using a one-way ANOVA. Given that comparisons were planned in this study, I used the least significant difference (LSD) test (Steel et al. 1997) as a multiple comparisons test to identify differences among management treatments for the above dependent variables. In addition, I ran two correlations to explore relationships between non-native grasses and both native grasses and clovers (native and non-native). I analyzed data collected in year 2 using the same procedure, with adjustments to data transformations to satisfy parametric assumption of ANOVA.

Responses to clipping and herbicide treatments are reported within the higher native grass density plots because this density is closer to the assumed target density in restoration plantings. The purpose of the native grass density treatment was to test for competitive interactions. Therefore, responses to native grass planting density are compared within the unclipped plots because clipping would likely lessen the difference between density treatments.

## Results

By the end of the growing season in year 3, only *Nassella* spp. had become well established and accounted for essentially all native grass LAI values. The majority of *Melica californica* and *Elymus glaucus* plants died during the first growing season, and *Koeleria macrantha* plants declined throughout the study. The use of native grass plugs instead of seed in the first year typically advances the relative growth of these species. It appears, however, that this effect was not accomplished in this study due to the unusually dry spring subsequent to their planting in year 1.

In year 1, *Erodium botrys* accounted for 94% of the total forb LAI measurements and was virtually eliminated when herbicide was applied in the herbicide-treated plots. There was significant variation across management treatments in both years 2 and 3 for native and non-native grass LAI values (year 2: $F = 3.6$, $p = 0.009$; $F = 49.2$, $p = 0.0001$; year 3: $F = 5.6$, $p = 0.0006$; $F = 11.1$, $p < 0.001$) and in year 3 for native clover density (year 2 (LAI): $F = 1.8$, $p = 0.1$; year 3 (density): $F = 2.4$, $p < 0.05$).

### Clipping

There were no detectable differences between the clip/herbicide and the no-clip/herbicide plots for either native or non-native grasses (Fig. 1; $p < 0.05$). In year 4 (the early winter of 2004), native grasses had half the LAI value in the clip/herbicide versus the no-clip/herbicide treatment, although this difference was not statistically significant ($F = 3.69$, $p < 0.09$; clip = 50% ± 4.8, no clip = 101% ± 26.0), and therefore, it supports the generally negligible response native grasses had to clipping in the spring. In contrast to year 3, non-native grasses responded negatively to clipping in year 2 (Table 4; $p < 0.05$).

Native clovers had 109% greater density in the clip/herbicide versus the no-clip/herbicide treatment in the final spring of the study (Fig. 2; $p < 0.05$). In year 4 (the early winter of 2004), significantly greater LAI values of native clovers in the clip/herbicide versus the no-clip/herbicide treatment support the positive response native clovers had to clipping in the prior spring dataset ($F = 15.7$, $p < 0.004$; clip = 18.6 ± 2.8, no clip = 6.3 ± 1.4).

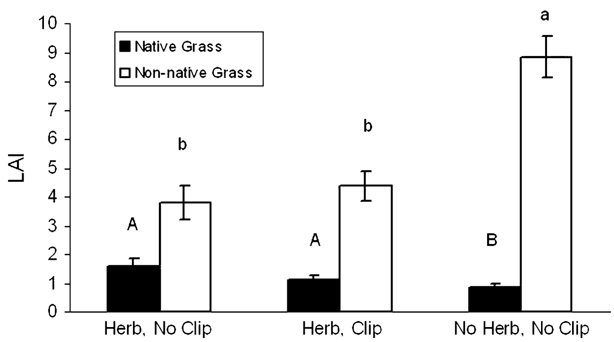


Figure 1. Year 3 (2004). The influence of herbicide (Herb) and clipping on the LAI for native and non-native grasses. Treatments not sharing a letter are significantly different ($p < 0.05$). Bars are 1 SE.

### Broadleaf Herbicide

Native and non-native grasses had significant yet opposite responses to broadleaf herbicide across years. Native grass response to the broadleaf herbicide treatment (no clip/herbicide vs. no clip/no herbicide) was not significant, negative, and positive in years 1 ($F = 2.0$; $p < 0.2$), 2 (Table 4; $p < 0.05$), and 3 (Fig. 1; $p < 0.05$), respectively. In contrast, non-native grasses had a positive, positive, and negative response to the broadleaf herbicide treatment in years 1 ($p < 0.05$), 2 (Table 4; $p < 0.05$), and 3 (Fig. 1; $p < 0.05$), respectively. Native clover response to herbicide-treated plots was strongly negative. The density of native clovers was 55% less in the no-clip/herbicide versus the no-clip/no-herbicide treatment in the final spring of the study (Fig. 2; $p < 0.05$).

### Native Versus Non-Native Clovers

Among the four native clover species seeded, *Trifolium willdenovii* and *T. bifidum* accounted for 70% of the density of native clovers and 65% of their total LAI in years 3 and 4 (the early winter of 2004), respectively.

Native and non-native clovers did not differ from each other in their densities in either the clip/herbicide or no-clip/herbicide treatments (Fig. 3; $p < 0.05$). Both clover types responded similarly to clipping, with almost twice as many individuals in the clip/herbicide versus the no-clip/herbicide plots, yet this was not statistically significant for non-native clovers (Fig. 3). In year 2, clovers responded

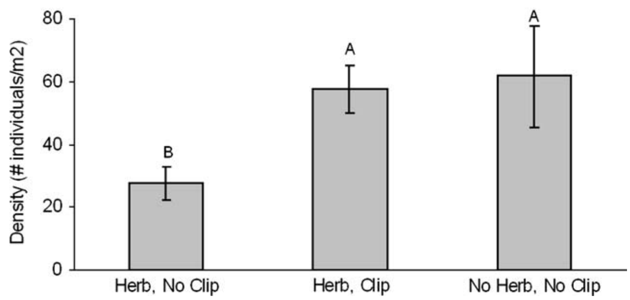


Figure 2. Year 3 (2004). The influence of herbicide (Herb) and clipping on the density of native clovers. Treatments not sharing a letter are significantly different ($p < 0.05$). Bars are 1 SE.

**Table 4.** LAI of all functional groups across tested treatments in year 2 (2003).

| *Functional Groups* | *Clip (Low Density)* | *Clip (High Density)* | *No Clip (Low Density)* | *No Clip (High Density)* | *No Herb, No Clip (High Density)* |
|---|---|---|---|---|---|
| Native grass | 38.0 (±9.7) B | 65.0 (±18.6) B | 39.4 (±5.1) B | 50.5 (±16.0) B | 105.0 (±17.4) A |
| Non-native grass | 326.0 (±23.8) C | 300.0 (±20.9) C | 679.0 (±63.3) B | 817.0 (±20.8) A | 251.0 (±34.3) C |
| Native clover | 11.7 (±1.2) n.s. | 13.0 (±2.6) n.s. | 17.3 (±3.4) n.s. | 12.3 (±5.9) n.s. | 24.7 (±6.1) n.s. |
| Non-native clover | NA (NA) NA | 33.7 (±7.9) n.s. | NA (NA) NA | 17.0 (±5.9) n.s. | NA (NA) NA |

Unless specified, all treatments were sprayed with broadleaf herbicide (Herb) in year 1. Clip (high density) and no clip (high density) include two treatments each: one with native clovers and one with non-native clovers. Within a functional group, treatments not sharing a letter are significantly different ($p < 0.05$). $\bar{X}$ values are followed by ± 1 SE. "n.s." indicates that the overall ANOVA was not significant, and therefore, a multiple comparison test was not used.

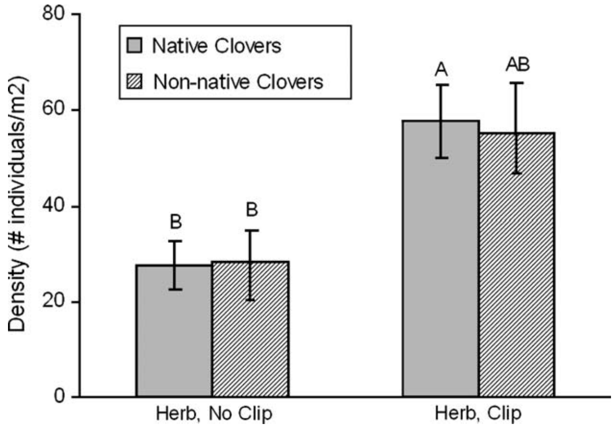


Figure 3. Year 3 (2004). The influence of clipping on the density of native versus non-native clovers. Treatments not sharing a letter are significantly different ($p < 0.05$). Bars are 1 SE.

similarly to management treatments, yet differences among treatments were not statistically significant overall (Table 4; $F = 1.8$, $p = 0.1$).

#### Planting Density of Native Grasses

In the unclipped plots, native grasses had almost twice the LAI value in the higher density native grass plots compared to the lower density plots (Fig. 4; $p < 0.05$). Although native grasses were planted at 22 and 48 plugs/$m^2$, by the fall of 2003 (year 3), density averaged 9 and 25 individuals/$m^2$ in the lower and higher density treatments, respectively. *Nassella* spp. accounted for only half of the planted plugs, yet plants in this genus produced on average 98% of the total LAI value of native grasses by year 3.

The LAI of non-native grasses was 40% less in higher density versus lower density native grass plots (both unclipped) (Fig. 4; $p < 0.05$). In the clipped plots, there was no difference in the LAI of either native or non-native grasses between the two density treatments. Overall, native and non-native grass LAI values were negatively correlated ($r = -0.54$, $p = 0.0009$).

In both unclipped and clipped plots, there was no detectable difference in native clover densities between the two native grass density treatments. There was also no significant correlation between non-native grasses (LAI) and clovers (density) ($r = 0.17$, $p = 0.31$).

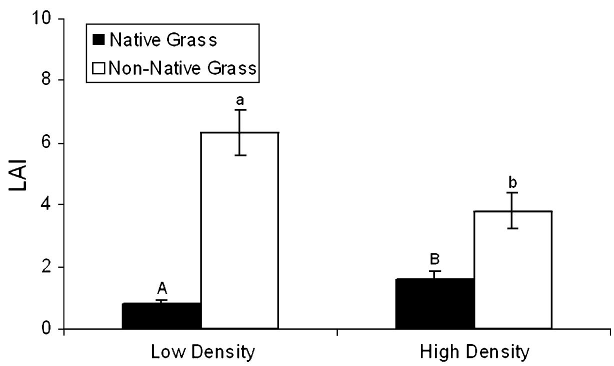


Figure 4. Year 3 (2004). The influence of native grass planting density on native and non-native grass cover. Treatments not sharing a letter are significantly different ($p < 0.05$). Bars are 1 SE.

#### Litter and PAR Measurements

By year 3, the herbicide/no-clip treatment had the greatest amount of litter, averaging twice as much as the herbicide/clip treatment ($F = 13.0$, $p = 0.0001$, LSD, $p < 0.05$; Table 5). In addition, the herbicide/no-clip treatment had greater litter than the no-herbicide/no-clip treatment. In year 2, the trends were similar, but most comparisons did not differ statistically. In general, litter increased between years 2 and 3.

In year 2, a greater percent of above-canopy light (PAR) was detected at ground level in the herbicide/clip treatment compared to either the herbicide/no-clip or the no-herbicide/no-clip treatment at both bunchgrass densities ($F = 70.1$, $p < 0.0001$; LSD, $p < 0.05$; Table 6). There was also a greater percent of PAR detected in the no-herbicide/no-clip versus the herbicide/no-clip treatment.

## Discussion

Native grasses and native clovers responded to the management treatments in different ways, underscoring the importance of testing and carefully applying management techniques when restoring multiple species groups. In the current study, native grasses did not respond as strongly to the management treatments as the native clovers; therefore, in determining an appropriate management strategy for both these groups, treatments that favor native clovers should be given greatest priority. The recommended management strategy to establish both native grasses and clovers would be one that applied clipping and did not apply broadleaf herbicide before planting. Ironically, I did not include a no-herbicide/clip management treatment in my design because I did not anticipate a negative response by clovers to initial herbicide treatments. In addition, the higher native grass density of 25 individuals/$m^2$ did not negatively affect clovers compared to 9 individuals/$m^2$, yet it did decrease the LAI of non-native grasses. Planting native grasses at a higher density would therefore maximize total native plant cover.

Interpretation of native grass results from this study should be limited to *Nassella* spp. because this was essentially the only native grass genus that survived during the initial planting. That *Nassella* spp. had much greater survival than the other planted species supports suggestions that this genus is particularly tolerant of disturbed sites and more xeric conditions relative to other upland native grass species (Bartolome 1981; Lulow et al. 2007). Selectively

**Table 5.** Litter depth (cm) among tested treatments in year 2 (2003) and year 3 (2004) of the study.

| Year | Clip (Low Density) | Clip (High Density) | No Clip (Low Density) | No Clip (High Density) | No Herb, No Clip (High Density) |
|---|---|---|---|---|---|
| 2 | 2 (±0.3) BC | 1.3 (±0.4) C | 2.1 (±0.5) BC | 2.9 (±0.4) AB | 1.9 (±0.2) BC |
| 3 | 3.3 (±0.4) C | 2.9 (±0.3) C | 5.4 (±0.6) AB | 6.5 (±0.5) A | 4.7 (±0.6) B |

Unless specified, all treatments were sprayed with broadleaf herbicide (Herb) in year 1. Within a year, treatments not sharing a letter are significantly different ($p < 0.05$). $\bar{X}$ values are followed by ± 1 SE.

seeding or planting other upland native grass species in microsites that maximize soil moisture might prove more successful.

### Clipping

The lack of a response by native grasses to early spring clipping over the 3 years was contrary to my expectations because I anticipated less light interference from non-native grasses in these plots. This result was consistent in both years 2 and 3, despite the fact that clipping reduced the LAI of non-native grasses in year 2, which in turn was likely responsible for increased light availability. The lack of a response by non-native grasses to clipping in year 3 likely resulted from a longer growth period between the final clipping treatment and sampling compared to year 2. Furthermore, when growth at the beginning of the growing season was measured in year 4 to capture native grass responses to clipping in the previous growing season, the LAI of native grasses was 50% less than that of native grasses in clipped plots with borderline significance ($p < 0.09$). Therefore, it is difficult to conclude from this study with confidence that clipping does not affect native grass growth. It appears that under the conditions of the experiment, early spring clipping either (1) does not have a significant impact on native grasses, either directly or indirectly, or (2) has a negative impact on their overall carbohydrate reserves, but this is compensated for by the release of competitive interference from non-native annual grasses, resulting in a negligible net impact.

The lack of a response by *Nassella* spp. to clipping in this study supports grazing studies conducted with both continuous and seasonal grazing regimes (Hatch et al. 1999; Hayes & Holl 2003*a*; Marty et al. 2003 [vegetative data]). However, other studies have found a positive response by *Nassella pulchra* to grazing (Dyer 2003 [unburned plots]; Bartolome et al. 2004 [spring grazing only]), as well as a negative response (Fehmi & Bartolome 2003; Marty et al. 2003 [reproductive data]; Bartolome et al. 2004 [species other than *N. pulchra*]). It therefore appears that site conditions, as suggested by Hayes and Holl (2003*a*), and/or the amount of senescent material interfering with light penetration to growth meristems, as suggested by Dyer (2003), play important roles in predicting responses of *N. pulchra* to grazing or clipping. The bunchgrasses in this study were young and small, likely making removal of vegetation more costly relative to larger individuals. It is also important to note, however, that first-year native grass seedlings are generally shorter than 6 cm in the early spring. Under this scenario, clipping at this height would reduce canopy cover of non-native annual grasses without the expense of lost tissue to native grasses.

Although the positive response to clipping by non-native clovers was not statistically significant, the trend of the results over the 2 years generally concurs with previous grassland studies in California (Talbot et al. 1939; Love 1944; Murphy et al. 1973; Hayes & Holl 2003*a*) and elsewhere (Noy-Meir et al. 1989; Antonsen & Olsson 2005) that have found clipping or grazing to be important in maintaining non-native clover and annual forb populations in grasslands. Furthermore, the results indicate that clipping may be an effective technique in restoring native clover populations.

Clipping also resulted in decreased litter and increased light at ground level. The amount of litter is a factor that has been reported to influence the productivity of grassland forbs (Talbot et al. 1939; Heady 1956). Although the results support other studies that have found litter and light availability important to annual forb growth, the relative importance of these factors cannot be determined from this study.

**Table 6.** PAR among tested treatments in 2003.

| Management Treatment | Percent of Above-Canopy PAR | Significance |
|---|---|---|
| Clip (low density) | 14.5 ± 0.9 | A |
| Clip (high density) | 19.3 ± 3.5 | A |
| No herb, no clip (high density) | 8.5 ± 1.8 | B |
| No clip (low density) | 3.5 ± 1.2 | C |
| No clip (high density) | 2.3 ± 0.6 | D |

Values are reported as the percent of the above-canopy PAR reaching ground level on a per-plot basis. Unless specified, all treatments were sprayed with broadleaf herbicide (Herb) in year 1. Treatments not sharing a letter are significantly different ($p < 0.05$). $\bar{X}$ values are followed by ± 1 SE.

### Broadleaf Herbicide

Broadleaf herbicide (i.e., 2,4-D) had a negative effect on native clovers and a mixed effect on native grasses. Therefore, I would use caution in applying broadleaf herbicide as a management tool when establishing communities with these groups of species, at least when the undesirable species is *Erodium botrys* and when the native grasses are beyond the initial seedling stage.

Non-native grasses had a significantly greater LAI value in sprayed plots in year 2, suggesting that they may have been released from competitive interference by *E. botrys*. It is not clear, however, why non-native grasses also responded significantly in the subsequent year but in the opposite direction. This result could have occurred if non-native grasses were self-inhibiting, particularly because they produced greater amounts of litter in sprayed plots. However, previous research investigating the effects of litter on non-native annual grassland in California suggests that given the average rainfall at this site and the presence of a previously tested species (*Bromus hordeaceus*) (Heady 1956; Bartolome et al. 1980; cf Heady et al. 1992), the non-native annual grasses would have increased yields with intermediate-to-high amounts of litter.

Native grasses likewise changed the direction of their response to herbicide between years 2 and 3 but in opposite directions to non-native grasses each year. This result, in addition to an overall negative correlation between these grass types, suggests that native grasses may have been responding to interference by non-native grasses in these treatments.

The substantial negative response to herbicide from native clovers was unexpected and needs further research, especially when considering that the total LAI of grasses was actually greater in unsprayed plots in year 3. The reported residual time of 2,4-D is less than 6 weeks, and at its highest application rate, 2,4-D persists in the soil for 30 days (U.S. Forest Service fact sheet by Information Ventures, Inc.). It therefore seems unlikely that the clovers in this study would be responding to the direct effects of residual herbicide 8 or 20 months after application. Ka et al. (1995) identified changes in microbial community composition with the application of 2,4-D in field studies, yet to my knowledge, investigations of potential indirect effects on the plant growth or survival have not been conducted. Additionally, Fabra et al. (1997) found deleterious effects of 2,4-D on *Rhizobium* sp. M4 isolated from peanut nodules in laboratory studies. Whether or not these results are applicable to my study would require field experimentation.

There was significantly more litter in sprayed plots in year 3, likely a result of higher LAI values of non-native grasses in these plots in year 2. It cannot be determined, however, if this litter was responsible for the lower densities of clovers in these plots.

#### Native Versus Non-Native Clovers

The non-native clovers used in this study have been tested specifically for suitability in California through production trials (e.g., Graves et al. 2001), so it is not surprising that they were able to establish at similar densities to clovers native to the region. Under the environmental conditions in this study, *Trifolium willdenovii* and *T. bifidum* had proportionally greater establishment success than the other native species. These species were also among the more common native forb species observed in a grassland survey of native plant populations in the larger region of this study (M. Lulow & T. Young, unpublished data). Because native and non-native clovers exhibit similar levels of productivity, further research using native clover species for applications where the goals are to enhance native flora abundance and provide suitable range forage is warranted.

#### Planting Density of Native Grasses

Non-native grasses responded negatively to the increase in native grass planting density in the unclipped plots, even though the resulting density in the higher density treatment may be considered low to exclude annual grasses, particularly because the *Nassella* spp. individuals were relatively small (Megan Lulow 2004, Irvine Ranch Conservancy, personal observation). The negative correlation across treatments further suggests that native and non-native grasses were competing. These results support previous studies conducted at both coastal and inland sites that found that seeded or planted native grasses, once mature and established, can resist invasion by non-native annual grasses (Seabloom et al. 2003; Corbin & D'Antonio 2004; Lulow 2006). In the clipped treatment, however, non-native grasses did not respond to the density treatment. Clipping may have reduced the difference in native grasses between the density treatments.

Contrary to my expectations, native clovers did not respond to differences in the relative amounts of native and non-native grasses between the high- and the low-density native grass treatments. The lack of a response by native clovers may be because (1) interference from native grasses is as great as from non-native grasses, (2) the relative proportion of native grasses needs to be higher than it was in this study in order to detect a response from native clovers, or (3) total grass amount is more important than grass type, at least beyond a certain level. Carlsen et al. (2000) investigated differences in native bunchgrass versus non-native annual grass neighborhoods on an annual native forb (*Amsinkia grandiflora*). Their results suggested that non-native annual grasses interfered more with *A. grandiflora* than native bunchgrasses, but this difference was only detectable below intermediate density levels. In contrast to this study, I did not remove non-native annual grasses from the plots with native grasses; therefore, the total amount of grass was likely beyond that where differences in interference between grass types may be detectable.

#### Future Research

The purpose of this study was to better understand the ecological impacts of commonly used management treatments on restoration of grassland groups in the first few critical years. Temporal factors, such as the impacts of clipping in successive years and the application of a fire regime, are additional considerations not addressed in this study. Further research conducted on communities 3–5 years into their restoration is needed to address the use of management strategies to promote long-term coexistence of native grasses and forbs.

**Implications for Practice**

- Communities with greater relative abundance of *Nassella pulchra* versus non-native annual grasses do not necessarily increase establishment success of native clovers. Further research investigating the significance of average plant size and overall grass productivity would be informative.
- Early spring clipping is an important management tool in restoring populations of native clovers, and significant impacts on the growth of *N. pulchra* were not detected in this study.
- Results from this study do not support the use of 2,4-D to minimize broadleaf weed competition 8–20 months prior to seeding native clovers.
- Because there was no difference in the density of seeded native and non-native clovers in either clipped or unclipped plots, further research investigating the efficacy of using native versus the more widely used non-native clovers for range improvement is warranted.

## Acknowledgments

This research was made possible by funding from the Audubon California Landowner Stewardship Program, a program funded through CALFED's Ecosystem Restoration Program Project (Willow Slough Rangeland Stewardship Project 01-N31). I would like to thank my advisor T. Young for his support throughout the project, J. Anderson of Hedgerow Farms for donating seed, both he and California Audubon for logistical support, and J. Goerrissen, L. Naito, A. King, and B. Bugg for assistance in experiment maintenance and data collection. I am especially grateful to R. Stewart for allowing the experiment to take place on his property and for his patience and trust with repeated site visits. Comments provided by T. Young, K. Rice, K. Holl, J. Goerrissen, K. Williams, and two anonymous reviewers greatly improved the presentation of this study.

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