# The Value of Oak Woodland Habitats as Control for Medusahead (*Taeniatherum caput-medusae*)[1]

**Elise S. Gornish,[2] Jeremy J. James,[3] and Emilio A. Laca[2]**

### Abstract

Although medusahead (*Taeniatherum caput-medusae*) is one of the most dominant invasive rangeland grasses in the West, we know surprisingly little about the environmental factors that drive medusahead abundance. Understanding the conditions that influence spread dynamics is central for developing effective monitoring, prevention and control programs.

We established grassland plant communities and added medusahead seed across a range of five densities (from 0 to 50,000 seeds per $m^2$) in open grassland and oak savannah habitat. We followed plants throughout the season to understand how habitat and seedbank dynamics affect underlying vital rates and overall density.

Oak woodlands reduced medusahead abundance by almost 300 percent, and this effect was greater later in the growing season. The negative effect of oak woodlands was almost an order of magnitude less for common competitive annual species. We also found that reproductive spike production was lower in the oak habitat than the open habitat; and that seeding rate had a negative relationship with seed produced per spikelet. These effects ultimately contributed to a reduction in medusahead reproductive output between habitats, across seeding rates. This work highlights the value of oak woodland habitats as an effective and sustainable way to control medusahead density and recruitment.

*Key words*: annual grass, conservation, grassland management, invasive plant, restoration

## Introduction

The winter annual grass medusahead (*Taeniatherum caput-medusae*), is one of the dominant invasive range species in the West. Originating in the Mediterranean, medusahead has already invaded 17 western states since it was first identified in Oregon in 1887 (McKell and others 1962). A variety of methods have been tested to control the noxious weed, including grazing, herbicide, and controlled burning (DiTomaso and others 2007). The continued aggressive spread of medusahead, however, suggests that current control efforts, even in the presence of an initial decline in weed density, are largely unsuccessful. A recent meta-analysis (J. James and others, in press) suggests that high variation of medusahead cover in response to control treatments is likely due in, large part, to underlying environmental factors such as habitat type or seedbank dynamics.

Indeed, several environmental factors have been identified as being particularly important filters for medusahead dominance and control. For example, as little as 5 percent tree cover can significantly reduce medusahead cover (Shlisky 2001). Certain soil characteristics can also play a role as well (for example, Nafus and Davies 2014),

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since medusahead has been shown to respond to soil fertility (Bovey 1959), and soil water content (Bansal and others 2014). Having an understanding of the relationship between environmental factors and medusahead dominance would be useful for developing more effective control techniques for the weed.

In order to understand how environmental factors might affect the underlying vital rates and overall density of medusahead, we investigated how seeding density (to simulate differences in the seedbank) and habitat type (open vs. oak) affect medusahead recruitment. Since the oak habitat provides less ideal conditions for medusahead through shading and precipitation interception, we expected medusahead density to be considerably lower in the oak habitat compared to the open habitat (Shlisky 2001). We also expected interactions among habitat type and seeding density since density dependence has been shown to operate within medusahead populations (Bovey 1959). Specifically, we expected that individuals experiencing less intraspecific competition (in other words, lower seeding densities) would respond to the comparatively higher resource open grassland habitat with a larger reproductive output (Archer and Detling 1984, Lee and Bazzaz 1980) compared to individuals experiencing less intraspecific competition because of reduced density stress (for example, Banyikwa 1988).

## Methods

### *Species description and site preparation*

Medusahead has rapid germination embedded in thatch or at the soil surface in the early winter after autumn rains. Seedlings (approximately 7 cm tall) emerge after late winter rains. As the plant grows, it produces several internodes, and can attain a full of height of 20 to 60 cm (Parish 1956). In May, after the production of four to five tillers, individuals will flower. Individual plants can produce between 15 to 23 spikelets, with each spike producing about 12 seeds.

In early fall of 2013, paired permanent plots (1 $m^2$) were installed in two habitat types (open grassland and oak woodland). Canopy cover was approximately 50 percent higher in the oak woodland habitat (mostly blue oak, *Quercus douglasii*, and interior live oak, *Q. wislizeni*) compared to the open habitat. In the oak woodland habitat, leaf litter was also substantial (mean = 501.8 grams, SD = 176.2 grams per $m^2$). Existing vegetation at all sites was initially removed by mowing and standing thatch was removed. The soil was solarized in an attempt to equalize soil conditions and reduce the seed bank. We applied soil solarization via clear 4 mm thick polyethylene tarps that covered the plots at the soil surface for approximately 14 days to encourage seed germination (depletion of the seed bank). Glyphosate (Roundup) was then applied to kill germinated plants.

Plots were hand seeded with one of five densities of field-collected medusahead (0, 100, 1000, 10,000, and 50,000 seeds per $m^2$; see Marañón and Bartolome 1989 for seed bank values), mixed in with 500 grams of medusahead thatch. Immediately following the addition of medusahead seed, we added 6,000 seeds each of neighboring grass species (annual rye, and brome) and 4,000 seeds of a clover mix (for a total of 16,000 neighbor seeds added) to maintain a realistic competitive environment (Marañón 1998; E. Gornish, unpublished data). Treatments were randomly assigned to plots within habitat level quadrats. Main factors were replicated four times for a total of 40 plots (two habitats × five seeding densities × four replicates = 40 plots).

### *Data collection*

We censused the plant density frequently during the growing season. Census periods coincided with important transitions in the life cycle of the medusahead plant. These included: germination in December 2013; emergence in April 2014; establishment in May 2014; and flowering culm production in June 2014. During each census period, the density of medusahead tillers as well as the density of all other live plants was estimated by counting live tillers within the 0.25 $m^2$ center subplot and multiplying by four.

In June 2014, we counted the total number of flowering spikes in each plot. At this time, we also bagged the spikes of 10 individuals in each plot with drawstring organza germination bags (7.6 x 10 cm). Three months later, we collected the bags and counted total seed number for each spike, and assessed percent germination by plating out all captured seeds.

### *Analysis*

We first analyzed the effect of habitat, seeding rate, census month (fixed factors), and replicate (random factor) on medusahead density with a multivariate model that included a Poisson error structure to accommodate count data. We then created a separate multivariate model for each demographic component of recruitment (spike number per plot, seed number per spike, percent germination, and finally, total reproductive output per plot [spike number per plot x seed number per spike × percent germination per spike]). These models included the explanatory variables of habitat and seeding rate (fixed factors), and replicate (random factors). The models describing spike number per plot and seed number per spike included a Poisson error structure to accommodate count data.

## Results

Medusahead density was significantly lower in the oak habitat (mean density = 82.3 tillers per $m^2$) than in the open habitat (mean density = 267.7 tillers per $m^2$) ($p < 0.001$), and this negative effect became more pronounced throughout the growing season ($p < 0.001$). Although the density of the common annual competitors was also slightly smaller in the oak habitat (mean density = 169.5 tillers per $m^2$) compared to the open habitat (mean density = 200 tillers per $m^2$) early in the growing season, this pattern disappeared by April 2014.

Medusahead reproductive spike production was five times greater in open grassland habitats (estimate = 2.22, SE = 0.08, z = 28.4, $p <0.001$). There was also a small, but significant positive relationship between spike production and seeding rate (estimate = 0.0003, SE = 0.0001, z = 26.7, $p <0.001$; fig. 1A). However, there was no interaction between habitat and seeding rate. Habitat did not appear to affect average seed number per spikelet (fig. 1B), but there was a small, negative relationship between seeding rate and seed number per spikelet (estimate = -0.0001, SE = 0.0004, z = -2.78, $p = 0.007$; fig. 1B). There was no effect of habitat, or seeding rate on percent germination of seeds produced across plots (fig. 1C). When these three factors are multiplied together to identify total reproductive output per $m^2$, we found that as main effects, habitat and seeding rate were not important drivers of recruitment. However, the interaction of habitat and seeding rate was important for driving differences in total reproductive output (estimate = 0.08, SE = 0.02, z = 4.2, $p <0.001$; fig. 1D).

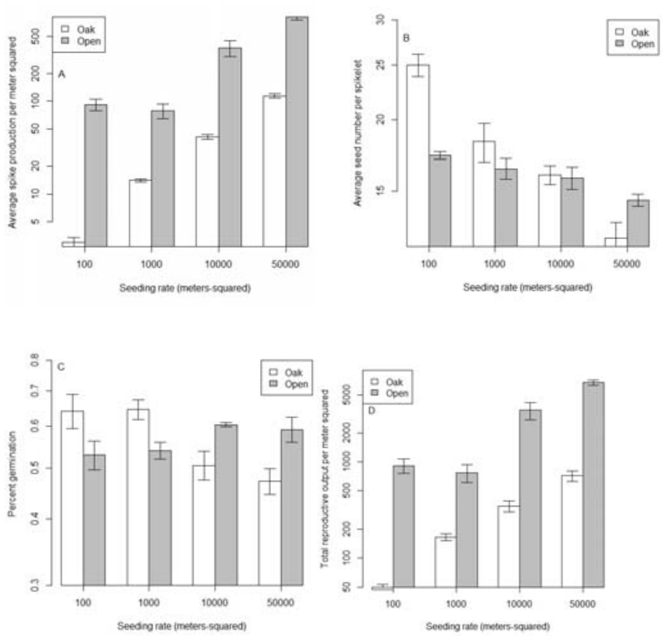


Figure 1—Components of medusahead recruitment across seeding rates per meter squared in open (gray bars) and oak (white bars) habitat. A) Spike production per; B) Seed number per spike; C) Percent germination of seeds per spike; D) Total reproductive output. Bars = means ± SE.

## Discussion

Although environmental variables are important drivers of population growth rate (for example, Jacquemyn and others 2010, Lehtila and others 2006), there is a surprising lack of research that investigates the relationship between habitat characteristics, vital rates and invasion (Ramula 2014). In order to clarify if habitat type and seedbank dynamics in fact play a role in mediating the dominance of medusahead, we investigated how medusahead density and recruitment are affected by oak habitats and different seeding rates.

To our knowledge, this is the first time a study has formally quantified the negative effect of oak woodland habitat on medusahead dynamics. As expected, we found that oak habitats provide a less ideal environment for medusahead, resulting in lower densities and lower reproductive spike production, compared to open habitats. We expect that one or more of the environmental factors associated with the high heterogeneity of resources associated with oak canopies (Marañón and Bartolome 1994), such as leaf litter and soil moisture (for example, Callaway and others 1991) indirectly reduced the competitive dominance of medusahead. Explicitly documenting the identity of the factors that mediate negative effects of oak habitat on medusahead would be helpful for developing a more nuanced understanding of variables that might contribute to variation in the success of medusahead control efforts.

We also found that seeding rate (a proxy for the seedbed) is an important driver of per spikelet seed production. This was not entirely unexpected as demographic factors are often driven by underlying seed or population size (for example, Ramula

2014). Although previous studies have also documented the effects of density on medusahead spike production (for example, Murphy and Turner 1959), studies investigating how the interactive effects of seed density and environmental factors operate across the life cycle of an invasive species are uncommon (Ramula and Buckley 2009). And, this type of information is needed for making predictions of future invasions of the weed (for example, Mangla and others 2011, Wallace and Prather 2013), as well as developing adequate control methods.

We found that medusahead recruitment ultimately responded to an interaction between seeding rate and habitat type where there was a relatively linear, positive relationship between seeding rate and total reproductive output in the oak habitat, but not in the open habitat. This suggests that the role of the seedbank in mediating medusahead dominance oak habitats is even more pronounced, in terms of recruitment, than in the open grassland habitat. This work demonstrates the integral role of oak woodlands for effective, continued management of medusahead, providing yet another piece of support for the continued development and maintenance of oak conservation strategies.

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# Thinning Interior Live Oak in California's Southern Sierra Nevada[1]

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### Abstract

This study describes a thinning and resprout control study in Madera County. The study site was a dense, 40-year old interior live oak stand (*Quercus wislizeni*) that originated from resprouting, with 100 percent canopy cover. Tree thinning was initiated in 1998 in cooperation with the local Resource Conservation District to evaluate thinning treatment to reduce first risk and to increase forage production. Three thinning treatments were evaluated: (1) thin one-third of the standing tree basal area (resulting in a post-thin basal area of 46 square feet per acre); (2) thin two-thirds of the standing tree basal area (resulting in a post-thin basal area of 27 square feet per acre); and (3) control/no thin (basal area of 73 square feet per acre). Because interior live oak is such a prolific sprouter, half of the thinned plots were treated with herbicides to prevent resprouting and to retain the open canopy structure. Canopy cover, diameter and height growth, and acorn production were monitored over a 13-year period. Periodic annual increment for basal area and volume was not significantly affected by the thinning treatment. Individual tree DBH growth was significantly increased with the thinning. 13 years after the thinning, the 1/3 treatment had virtually identical volume to the control, although the 2/3 thinning treatment had significantly less volume per acre. The sprout control treatment had no significant effect on the overstory tree growth, although a more open understory was maintained by controlling resprouting. Individual tree acorn production was significantly increased as a result of the thinning treatments. Thinning appears to be a promising management tool to diversify stand structure in dense live oak stands in the Southern Sierra, increasing economic value for livestock use and reducing wildfire risk.

*Key words*: interior live oak, oak thinning

## Introduction

Interior live oak (*Quercus wislizeni*) is widespread in California, occurring on 16 percent of California's oak woodlands (Waddell and Barret 2005). It is characterized by a vigorous sprouting capacity (Fryer 2012, Plumb and McDonald 1981). It is well-adapted to fire, and shows a rapid response to top-killed fire damage (Plumb and Gomez 1983).

The rapid regrowth of interior live oak results in very high density canopy cover classes following wildfire, which has a negative effect on forage production, water yield, and some wildlife species (Fryer 2012). Interior live oak is predominantly found on private lands (78 percent of the total cover type), making multiple use management and economic livelihood of private owners a key component of long term conservation (Waddell and Barrett 2005).

Dense stands of interior live oak are widespread throughout the Sierra Nevada foothills. To date, there have been no investigations of the effects of thinning on interior live oak stand characteristics. Bonner and other (2008) have shown promising results with thinning of coast live oak (*Quercus agrifolia*), a coastal live

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oak with similar silvical characteristics to interior live oak. This suggests that there could be positive effects on stand structure from thinning treatments.

## Methods

The Coarsegold Resource Conservation District (RCD) has had an active program to reduce impacts from catastrophic wildfires on a diverse array of wildland vegetation types, and provides technical assistance and support for cost-share payments to landowners with appropriate silvicultural and restoration strategies. They requested the assistance of the University of California to develop thinning recommendations on interior live oak to guide landowner actions.

A study site on a private ranch was selected near the town of North Fork, California in Madera County. The study site was at an elevation of 579.12 m (1900 ft), and was seasonally grazed as part of a cow-calf operation. The study site had developed from a rangeland clearing 40 years earlier. The overstory interior live oak canopy cover was close to 100 percent. The stand has a very high fire risk, and had no forage production due to the heavy shading of the understory. The area was representative of large acreages of similar, dense interior live oak stands in the Southern Sierra.

The study was designed with two thinning levels (thin one-third, and two-thirds of the basal area), and an unthinned control. There were 6 replications of each thinning level. Each replication was 0.1 acres in size. On half of the replications, the stumps were treated with herbicides (glyphosate), to prevent resprouting of the cut stumps. The trees were harvested in the winter of 1998. Trees were selected for harvest to accomplish the basal area retention goals for each treatment. The herbicide treatments were applied at the time of harvesting. Rings of the harvested trees were counted, and the stand age of 40 years was confirmed. Table 1 below shows the summary statistics of the study site.

**Table 1—General summary statistics for interior live oak thinning treatment in Madera County, California (standard errors shown in parentheses)**

| Treatment | Basal area (sq. ft./ac) | Volume (cu. ft./ac) |
|---|---|---|
| Control | 95.3 (5.6) | 1876 (306) |
| Thin 1/3 | 48.5 (2.5) | 1387 (167) |
| Thin 2/3 | 26.8 (1.5) | 769 (103) |

Data was collected on all residual trees in the study area in 1998, 2002 and 2010. At each measurement, diameter at breast height (1.37 m, DBH) and total height was calculated. From these figures, merchantable volume to a 5.08 cm (2 inch) small end diameter was calculated, using the volume equations in Pillsbury and Kirkley (1984).

Crown radius of all residual trees was taken in two directions in 2010 to calculate overstory canopy cover percent. The canopy radius of the resprouting cut stumps was also measured in two directions in 2010 to calculate the understory canopy cover percent.

Acorn production was evaluated in 2000, 2001 and 2003 on all residual trees using the visual estimation methodology described by Graves (1980). All trees were placed into one of the four classes described by Graves (Class 1 = no acorns; Class 2 = acorns visible on close exam; Class 3 = acorns readily visible, don't cover entire tree; Class 4 = acorns readily visible, cover entire tree).

# Results

## *Volume and basal area growth*

Figures 1 and 2 show the 13-year total volume and basal area per acre for the three treatments. The one-third thinning treatment had virtually the same volume as the unthinned control after 13 years. Both the one-third and two-thirds thinning treatments were growing at an increasing rate in both volume and basal area, while the control growth was decreasing over the study period. The replications with stump sprout control were combined with those without herbicide treatment, since understory treatment had no significant effect on volume or basal area. Expressed as a compound annual growth percent, the two-thirds thinned treatment grew at 5.1 percent, the one-third thinned treatment grew at 3.8 percent, and the unthinned control grew at 1.7 percent.

Table 2 compares the 13-year periodic growth per acre and for individual trees. There was no significant difference in per acre volume or basal area periodic annual growth, although the one-third treatment had the highest numerical growth rate. Individual tree DBH growth was significantly higher in the two-thirds thinning treatment, growing over 4.5 times faster than the unthinned control.

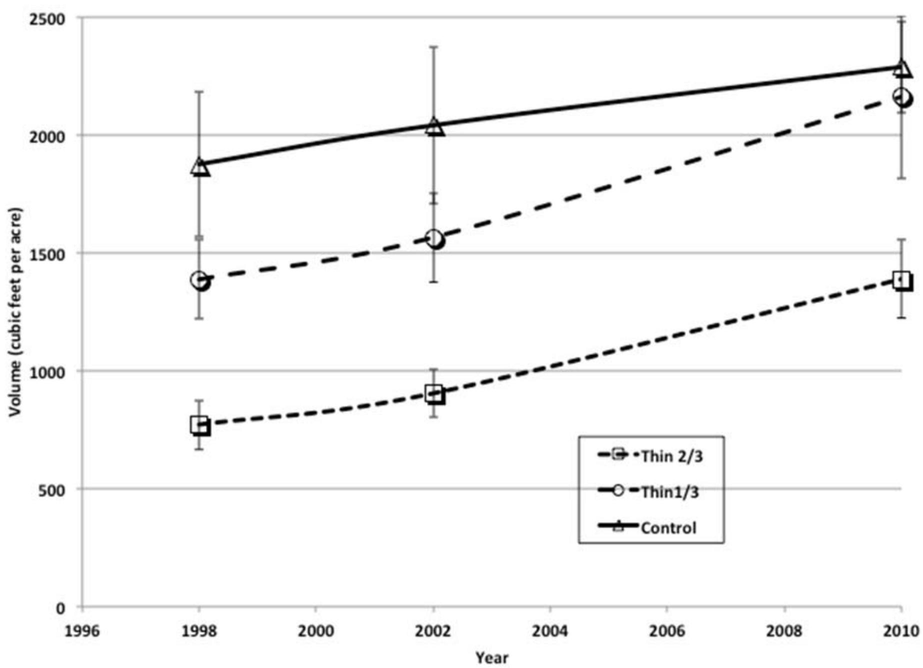


Figure 1—Volume per acre for interior live oak thinning treatments from 1998 through 2010.

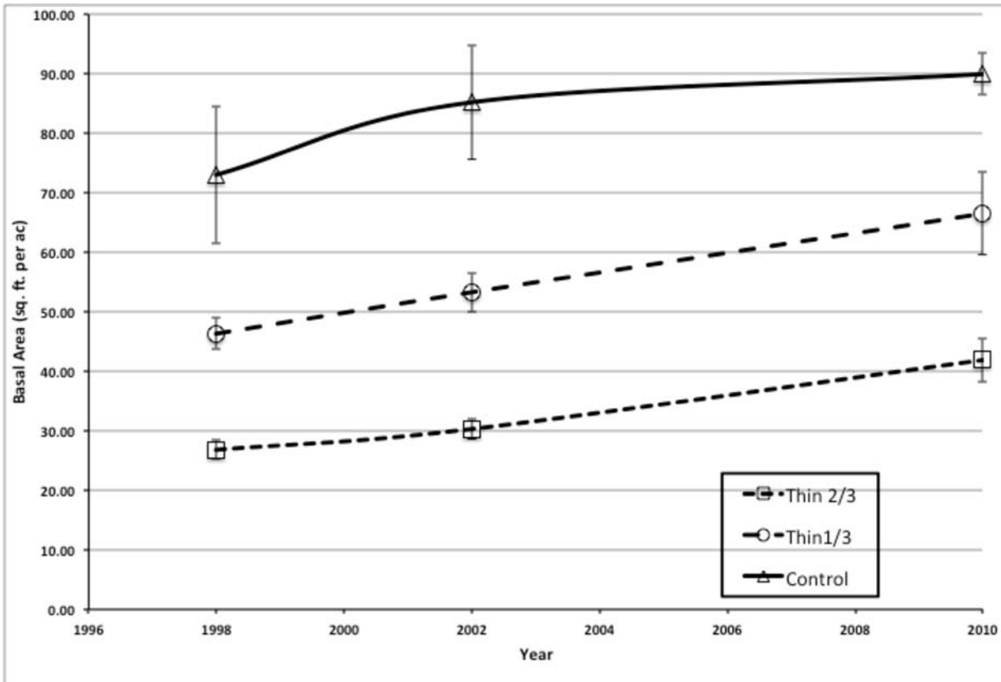


Figure 2—Basal area per acre for interior live oak thinning treatments from 1998 through 2010.

**Table 2—13-year changes in periodic annual increment and per tree measurements (means with different letters are significantly different at the 0.05 level)**

| Treatment | Vol. growth (cu.ft./ac/yr.) | BA growth (sq.ft./ac/yr.) | DBH growth (inches/tree/yr.) |
|---|---|---|---|
| Control | 59.9 | 1.3 | 0.03 A |
| Thin 1/3 | 78.5 | 1.4 | 0.08 AB |
| Thin 2/3 | 51.7 | 1.2 | 0.14 B |
| Significance | N.S. | N.S. | Sign. 0.05 |

## *Overstory and understory crown cover and sprout growth*

Figure 3 shows the overstory and understory crown cover after 13 years. The overstory cover was significantly affected by thinning intensity, and the understory cover was significantly affected by the stump herbicide treatment. Stump herbicide treatment did not affect the overstory cover, except for the two-thirds thinning, which had a 20 percent greater canopy cover when the stump were treated. The amount of understory cover was not affected by the thinning intensity. Table 3 shows the effect of thinning on sprout height and cover. The treated stumps had smaller canopy cover and very short sprout heights. The untreated stumps had sprouts of 1.83 to 2.44 m (6 to 8 ft) in height, and a cover of 12 to 16 percent, showing that thinning without stump treatment results in a significant ladder fuel and high fire risk, while thinning with sprout control had reduced fire risk.

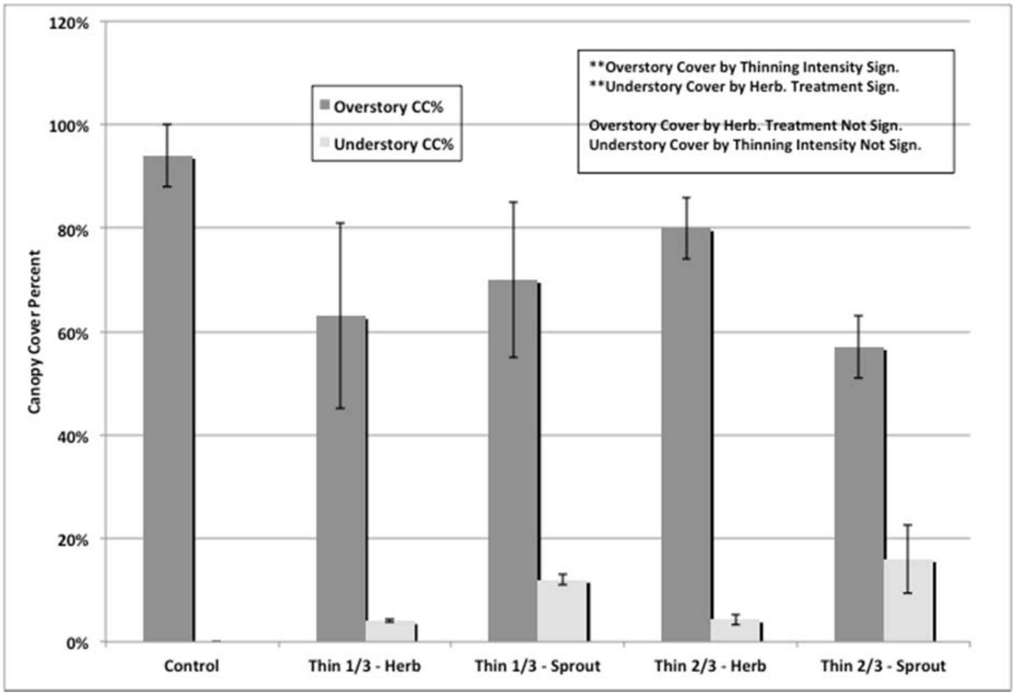


Figure 3—Overstory and understory canopy cover in 2010 by thinning and stump treatments.

**Table 3—13-year sprout height and understory canopy cover by thinning treatment**

| Treatment | Sprout height (ft.) | Sprout cover (pct.) |
|---|---|---|
| Thin 2/3 basal area | | |
| No sprout control | 8.4 | 16 pct. |
| Sprout control | <1 | 4 pct. |
| Thin 1/3 basal area | | |
| No sprout control | 6.1 | 12 pct. |
| Sprout control | <1 | 4 pct. |
| Significance | Sprout control sign. at 0.01; thin intensity N.S. | Sprout control sign. at 0.01; thin intensity N.S. |

## *Acorn production*

Figure 4 shows the probability of acorn production for the unthinned control and the two thinning intensities. For the 3 years sampled (2, 3 and 4 years after the thinning), there was a significant treatment effect from the thinning on the probability that a tree would have acorns (Class 2, 3 or 4). It will be necessary in future studies to determine if this has an impact on per acre acorn production, since thinning reduces the number of trees per acre and canopy cover.

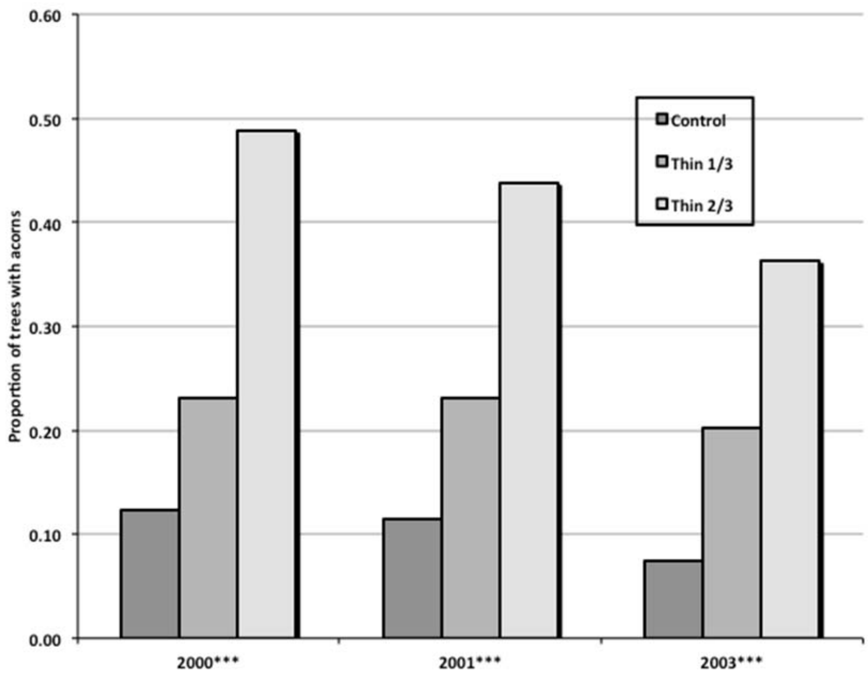


Figure 4—Proportion of trees with acorns for the three thinning treatments. Significance evaluated with Chi-square analysis. *** denotes significant at 0.01 level.

## Discussion

This study was useful in describing changes in interior live oak stand structure after thinning and sprout control. Over the 13 years in the study, there were no significant stand level growth differences from the thinning treatments, although the one-third thinning level had reached the same per acre volume level as the unthinned control.

The most significant stand level thinning impact is in individual tree growth. The two-thirds thinned stands were growing on average over four times greater than the unthinned stand. Over time, we would expect the thinned stands to have larger individual trees, that approach the unthinned stand in canopy cover and per acre volume. The thinning also significantly increased the probability of acorn production.

This study was designed to evaluate if thinning reduced the fire risk for landowners with interior live oak. This showed that thinning alone resulted in significant resprouting of the residual stumps, causing high risk of catastrophic wildfire from fuel ladders. Herbicide treatment of the residual stumps maintained a very low level of understory fuel ladders. It will be important for any fuel thinning to reduce the overtory crown cover, as well as treating the stumps in order to reduce fire risk.

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