

# Effects of Seedling Protectors and Weed Control on Blue Oak Growth and Survival<sup>1</sup>

Douglas D. McCreary<sup>2</sup> Jerry Tecklin<sup>2</sup>

**Abstract:** Two factors limiting successful recruitment of planted blue oak (*Quercus douglasii*) seedlings are dry soils and animal damage. Many approaches have been used to mitigate these factors including several types of protective cages and alternative methods of weed control. This study examined how treeshelters, screen cages and varying intensities of weed removal affect the establishment and growth of blue oak seedlings. After 5 years, seedlings protected with treeshelters had higher survival, greater diameter, and were taller than those in screen cages. Seedlings receiving no weed control had lower survival, shorter height, and smaller diameter than those with the two highest intensities of weed removal. This study suggests that treeshelters are a promising tool for regenerating blue oaks in California and that providing adequate weed control can improve the growth and survival of planted seedlings.

Blue oak (*Quercus douglasii*) is one of several species of native California oaks that is reported to be regenerating poorly in some locations (Bolsinger 1988, Muick and Bartolome 1987). Recent studies indicate that a variety of factors limit natural recruitment, including herbivory by deer, livestock, and rodents; defoliation by insects; root clipping by gophers; girdling by voles; and limited soil moisture induced by competing vegetation. These same factors can also prevent successful establishment of planted seedlings or acorns (McCreary 1990).

Many devices are used to protect planted seedlings from damage by animals, with varying degrees of success. Some of the more common products are plastic mesh cages, cylinders made from aluminum window screen, cages of chicken wire, and hardwire cloth buried in the ground. One relatively new product is called a treeshelter. These are rigid, translucent, double-walled plastic cylinders, developed in England and used there for more than 10 years (Potter 1988). They are reported to not only protect seedlings from a variety of animals, but also stimulate aboveground growth.

Another factor that can severely limit the survival and growth of oak seedlings on many rangeland sites is severe competition from grasses and forbs. Such competition can create extremely dry soil conditions that can be lethal to both natural seedlings and planted oaks (Griffin 1971). Some researchers believe that plant competition on many hardwood rangelands is greater today than it was before the introduction and establishment of exotic Mediterranean annuals, which have displaced many native perennials (Welker and Menke 1987). These annual plants absorb more soil moisture in the spring than the native perennial grasses, and consequently, create a drier environment. This makes it more difficult for oak seedlings to become established. Because of the adverse effects of such competition, researchers and practitioners have found controlling weeds around oak plantings necessary to obtain adequate survival and growth. Without weed control, animal damage problems are also generally greater, because dense weeds provide a favorable habitat for animals such as grasshoppers and voles, which can seriously damage young plants (Tecklin and McCreary 1993).

A variety of techniques have been used to eliminate weeds, including mulch, herbicides, scalping and mowing. Though studies comparing weed control to no weed control have demonstrated the advantage of weed removal (Adams and McDougald 1995), we are aware of no research on the effectiveness of varying intensities of weed removal on the field performance of blue oak seedlings.

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<sup>1</sup> An abbreviated version of this paper was presented at the Symposium on Oak Woodlands: Ecology, Management, and Urban Interface Issues, March 19-22, 1996, San Luis Obispo, Calif.

<sup>2</sup> Natural Resources Specialist and Staff Research Associate, respectively, with the Department of Environmental Science, Policy and Management, University of California, Berkeley. Mailing address: 8279 Scott Forbes Road, Browns Valley, CA 95918.

Our objectives in this study were to determine how different types of aboveground protection, and different intensities and durations of weed control, would affect the growth and survival of transplanted blue oak seedlings.

## Study Area and Methods

In early February 1991, we planted 160 1-year-old blue oak seedlings at the University of California Sierra Foothill Research and Extension Center, 30 km northeast of Marysville, California. Seedlings had been raised at the California Department of Forestry and Fire Protection Nursery in Davis, California, and were from acorns collected from a single tree growing approximately 5 km from the planting site. Seedlings were planted on a 2.1-m spacing in a fenced research area inaccessible to deer and livestock. Treatments included four levels of weed control (none, and weed-free circles of 0.6-, 1.2-, and 1.8-m diameter), and two types of protection (60-cm-tall screen cages or 1.2-m-tall treeshelters). Four blocks of 40 seedlings were established. Within each block, each weed-control treatment consisted of two adjacent 5-seedling rows, which were randomly positioned. One of these rows was randomly assigned to be protected with screen cages, while the other row was covered with treeshelters.

At the time of planting, through summer's end, the weed-free circles were created and maintained by scalping with hoes and occasional hand-pulling. Before planting, planting holes were augured to a depth of 60 cm using a tractor-mounted 15-cm diameter auger. A 21-g, slow-release fertilizer tablet (20-10-5 NPK) was placed approximately 30 cm deep within each hole. At the end of each of the next five growing seasons, we evaluated survival, total height, and basal diameter of all seedlings. During the second growing season, two of the four replications were randomly selected for a continuation of the weed-control treatments. That is, during this second season, those planting spots receiving the three weed-control treatments (0.6, 1.2, and 1.8 m circles) were maintained by a combination of hoeing and hand pulling. The other two replications were not treated, so there was a reinvasion of some weeds in the circles, though these areas had fewer weeds than the untreated areas. After the second year, no additional weed removal was provided.

All survival data were initially collapsed to frequencies and analyzed by a chi-square test. In instances where chi square indicated significant ( $P \leq 0.5$ ) differences among weed-control treatments, survival percentages were calculated for all weed-control/protection combinations within blocks, transformed by an arcsine transformation, and analyzed by an analysis of variance for a split-plot design with protection treatments nested within weed-control treatments. Height and diameter data were also analyzed using ANOVA for a split-plot design. When we observed significant ( $P \leq 0.05$ ) differences among weed-control treatments, a Tukey's multiple comparison test was performed to determine which treatments were significantly different from each other. We also tested for interactions between seedling-protection and weed-control treatments. To determine if there were significant differences between seedlings receiving weed control for either 1 or 2 years, a split-split plot ANOVA was performed. All differences stated as significant are at the  $P \leq 0.05$  level.

## Results

### Survival

During each growing season, survival of seedlings in treeshelters or tubes was significantly higher than survival in screen cages (*table 1*). The absolute differences between shelter types increased each successive year: survival of

seedlings in treeshelters remained relatively constant, while survival of seedlings in screen cages decreased each year. From the third year on, average survival in the treeshelters was twice that in the screens.

After the first growing season, no significant differences in survival among weed treatments were detected (*table 1*). By the second year, however, there were significant differences among weed treatments, with the control having significantly lower survival than the two treatments with the greatest intensities of weed removal. By the fourth growing season (1994), average survival of lowest intensity weed removal (0.6-m circles) was significantly greater than the survival of the no-weed-removal treatment. After the first growing season, average survival decreased 20 percent for seedlings where weed control was not maintained, but went down only 10 percent in blocks where the weed treatment was continued. After each subsequent growing season (when no further weed treatments were continued), survival decreased slightly, but at approximately the same rate for seedlings provided with weed control for either 1 or 2 years. There were significant interactions between protection and weed treatment in 1993 and 1995.

## Height

From the first growing season onward, seedlings in tubes were significantly taller than those in screens (*table 2*). The absolute difference in height between these treatments also increased each successive growing season, and by the third field season, seedlings in tubes were, on average, approximately 1 meter taller than those in screens. During the first year of the study there were also significant differences among weed-control treatments, with seedlings receiving the greatest weed control being significantly taller than those having no weed control, or the smallest diameter weed-free circles (*table 2*). By the second growing season, these

**Table 1—Average survival (pct) of seedlings protected with different devices, and receiving different intensities and intervals of weed control<sup>1</sup>**

| Treatment               | Growing Season    |                    |                    |                   |                   |
|-------------------------|-------------------|--------------------|--------------------|-------------------|-------------------|
|                         | 1991              | 1992               | 1993               | 1994              | 1995              |
|                         | ----- pct -----   |                    |                    |                   |                   |
| <b>Protection</b>       |                   |                    |                    |                   |                   |
| Screen cage             | <sup>a</sup> 71.3 | <sup>a</sup> 47.5  | <sup>a</sup> 41.3  | <sup>a</sup> 38.8 | <sup>a</sup> 32.5 |
| Treeshelter             | <sup>b</sup> 90.0 | <sup>b</sup> 83.8  | <sup>b</sup> 83.8  | <sup>b</sup> 81.3 | <sup>b</sup> 81.3 |
| <b>Weed intensity</b>   |                   |                    |                    |                   |                   |
| None                    | 67.5              | <sup>a</sup> 42.5  | <sup>a</sup> 40.0  | <sup>a</sup> 37.5 | <sup>a</sup> 32.5 |
| 0.6-m circle            | 80.0              | <sup>ab</sup> 67.5 | <sup>ab</sup> 57.5 | <sup>b</sup> 60.0 | <sup>b</sup> 57.5 |
| 1.2-m circle            | 87.5              | <sup>b</sup> 75.9  | <sup>b</sup> 75.0  | <sup>b</sup> 70.0 | <sup>b</sup> 65.0 |
| 1.8-m circle            | 87.5              | <sup>b</sup> 77.5  | <sup>b</sup> 77.5  | <sup>b</sup> 72.5 | <sup>b</sup> 72.5 |
| <b>Weeding interval</b> |                   |                    |                    |                   |                   |
| 1 year                  | 71.3              | <sup>a</sup> 51.3  | <sup>a</sup> 48.8  | <sup>a</sup> 47.5 | <sup>a</sup> 42.5 |
| 2 years                 | 90.0              | <sup>b</sup> 80.0  | <sup>b</sup> 76.3  | <sup>b</sup> 72.5 | <sup>b</sup> 71.3 |

<sup>1</sup> Growing seasons and treatment types with different letters are significantly different ( $P \leq 0.05$ ) by a chi-square test for protection and weeding-interval treatments, and by a Tukey's test for weed-intensity treatments.

**Table 2—Average height (cm) of seedlings protected with different devices, and receiving different intensities and intervals of weed control<sup>1</sup>**

| Treatment               | Growing Season                 |                    |                     |                     |                     |
|-------------------------|--------------------------------|--------------------|---------------------|---------------------|---------------------|
|                         | 1991                           | 1992               | 1993                | 1994                | 1995                |
|                         | ----- cm -----                 |                    |                     |                     |                     |
| <b>Protection</b>       |                                |                    |                     |                     |                     |
| Screen cage             | <sup>a</sup> 28.6 <sup>a</sup> | <sup>a</sup> 33.0  | <sup>a</sup> 71.6   | <sup>a</sup> 76.4   | <sup>a</sup> 94.0   |
| Treeshelter             | <sup>b</sup> 45.8              | <sup>b</sup> 96.1  | <sup>b</sup> 163.8  | <sup>b</sup> 183.4  | <sup>b</sup> 211.9  |
| <b>Weed intensity</b>   |                                |                    |                     |                     |                     |
| None                    | <sup>a</sup> 30.2              | <sup>a</sup> 39.2  | <sup>a</sup> 81.1   | <sup>a</sup> 105.0  | <sup>a</sup> 106.8  |
| 0.6-m circle            | <sup>a</sup> 30.7              | <sup>ab</sup> 54.7 | <sup>ab</sup> 113.1 | <sup>a</sup> 110.9  | <sup>ab</sup> 149.9 |
| 1.2-m circle            | <sup>ab</sup> 39.9             | <sup>bc</sup> 71.4 | <sup>bc</sup> 127.4 | <sup>ab</sup> 137.0 | <sup>b</sup> 162.0  |
| 1.8-m circle            | <sup>b</sup> 48.0              | <sup>c</sup> 94.8  | <sup>c</sup> 149.4  | <sup>b</sup> 166.7  | <sup>b</sup> 192.9  |
| <b>Weeding interval</b> |                                |                    |                     |                     |                     |
| 1 year                  | 36.4                           | <sup>a</sup> 56.7  | <sup>a</sup> 105.1  | 114.5               | 151.5               |
| 2 years                 | 38.0                           | <sup>b</sup> 72.3  | <sup>b</sup> 129.0  | 139.2               | 157.5               |

<sup>1</sup>Growing seasons and treatment types with different letters are significantly different ( $P \leq 0.05$ ) by Analysis of Variance for protection and weeding-interval treatments and by a Tukey's test for weed-intensity treatments.

differences were even greater. The absolute difference between controls and weed-removal treatments was greatest after the fifth growing season. In the second growing season (1992), half of the plots received a second year of weed removal. Seedlings that were maintained weed-free for 2 years were significantly taller after the second and third growing seasons. During the next two growing seasons, differences in height between these two groups were no longer significantly different. There was a significant interaction between protection and weed treatment in 1992 only.

## Diameter

Patterns in basal diameter were similar to those for height, but did not commence as early. During the first field season, no difference in diameter between seedlings with different protectors was detected (*table 3*). By the second growing season, however, seedlings in treeshelters had significantly larger diameters. Over time, the differences between these two treatments continued to increase, and by the fifth year, average diameter of seedlings in treeshelters was approximately 2.5 times greater than the diameter of those in screens.

During the first year, we detected significant differences in diameter among weed-control treatments; seedlings from the two treatments with the most weed removal were significantly greater in diameter than the two with the least (*table 3*). The absolute difference in diameter between treatments tended to increase over successive years. In contrast to height, the most pronounced increases in average diameter between seedlings that received weed removal for either 1 or 2 years were during the last two growing seasons. There were no significant interactions.

## Discussion

Our data suggest that both shelter type and the intensity and duration of weed control can dramatically affect the field performance of planted blue oak seedlings. From the first growing season, seedlings protected with treeshelters grew much taller than seedlings in screens. This is consistent with results from a previous study that compared these shelter types for valley oak (*Q. lobata*) (McCreary and Tecklin 1993). In another study with blue, valley, and interior live oaks (*Q. wislizenii*), however, there was little difference in survival or height growth between seedlings protected with treeshelters and those protected with screen cages (Costello and others 1996).

Our study also found that seedlings in treeshelters did not initially have larger diameters, and as a result, were somewhat spindly. Some early studies with oaks in England found that if shelters were removed after only 3 years, a proportion of the seedlings had not attained sufficient girth to support the crown and needed to be staked to the treeshelter stakes to keep them upright (Potter 1991). Our results suggest that treeshelters do cause an initial reduction in the diameter-to-height ratios of blue oaks. However, even during the second growing season, seedlings in tubes began to increase in diameter at a far greater rate than those in screen cages. By the fifth growing season, seedlings in tubes had not only larger height and diameter, but larger diameter-to-height ratios as well. In late fall 1995, we removed all but the bottom 20 or 40 cm of all treeshelters (which we left to protect the bases of the seedlings from voles and to compare the effectiveness of different heights in providing this protection). None of the seedlings fell completely over, though four or five did lean somewhat afterwards. These were all very small seedlings that had small (<1.5 cm) basal diameters and either were shorter than the tops of the tubes or had grown only slightly above. All of the other larger seedlings were not affected by removal of the tubes. Our general impression is that once the seedlings grow above the top of the treeshelters and begin to move in response to wind, they allocate more energy to

Table 3—Average basal diameter (mm) of seedlings protected with different devices, and receiving different intensities and intervals of weed control<sup>1</sup>

| Treatment               | Growing Season   |                   |                   |                   |                   |
|-------------------------|------------------|-------------------|-------------------|-------------------|-------------------|
|                         | 1991             | 1992              | 1993              | 1994              | 1995              |
|                         | ----- mm -----   |                   |                   |                   |                   |
| <b>Protection</b>       |                  |                   |                   |                   |                   |
| Screen cage             | 4.8              | <sup>a</sup> 4.9  | <sup>a</sup> 7.8  | <sup>a</sup> 9.2  | <sup>a</sup> 10.8 |
| Treeshelter             | 4.8              | <sup>b</sup> 6.7  | <sup>b</sup> 10.5 | <sup>b</sup> 15.8 | <sup>b</sup> 24.7 |
| <b>Weed intensity</b>   |                  |                   |                   |                   |                   |
| None                    | <sup>a</sup> 4.2 | <sup>a</sup> 4.4  | <sup>a</sup> 6.1  | <sup>a</sup> 7.5  | <sup>a</sup> 6.7  |
| 0.6-m circle            | <sup>a</sup> 4.3 | <sup>b</sup> 5.3  | <sup>ab</sup> 8.1 | <sup>a</sup> 10.4 | <sup>b</sup> 17.6 |
| 1.2-m circle            | <sup>b</sup> 5.2 | <sup>ab</sup> 5.8 | <sup>b</sup> 9.6  | <sup>a</sup> 13.1 | <sup>b</sup> 19.7 |
| 1.8-m circle            | <sup>b</sup> 5.7 | <sup>b</sup> 7.7  | <sup>c</sup> 12.8 | <sup>b</sup> 19.0 | <sup>b</sup> 26.8 |
| <b>Weeding interval</b> |                  |                   |                   |                   |                   |
| 1 year                  | 4.8              | 5.0               | <sup>a</sup> 8.2  | <sup>a</sup> 10.2 | <sup>a</sup> 15.6 |
| 2 years                 | 4.9              | 6.5               | <sup>b</sup> 10.1 | <sup>b</sup> 14.4 | <sup>b</sup> 20.4 |

<sup>1</sup>Growing seasons and treatment types with different letters are significantly different ( $P \leq 0.05$ ) by Analysis of Variance for protection and weeding-interval treatments and by a Tukey's test for weed-intensity treatments.

radial growth and their diameter increases. Simultaneously, the rate of height growth slows down. The overall result is that by the second or third growing season, the seedlings are simply much larger than their screened counterparts. We believe that in a wildland setting, a greater initial growth rate will confer a substantial advantage to seedlings, because they will grow more rapidly to a height at which they can withstand browsing pressures. Without protection, oak seedlings can remain stunted for years (White 1966). By providing a method to stimulate initial growth, treeshelters may not only improve the chances that a young seedling will eventually become a tree, but greatly hasten the process as well. However, it is important to leave the shelters in place until the seedlings have grown well above the tops of the tubes, so that they develop sufficient diameter to support the crown.

Determining exact causes for faster growth of seedlings in treeshelters versus screened cages is somewhat difficult. Treeshelters have been reported to stimulate aboveground growth of trees through a combination of moisture conservation, increased temperatures, and elevated carbon dioxide levels (Potter 1991). However, we observed that animals can also influence seedling growth rates. Because ground vegetation surrounding the scalped circles was not controlled, vegetative cover near seedlings was extensive. This apparently provided a favorable habitat for both voles and grasshoppers. The screens were much harder to maintain than the tubes, and consequently these animals damaged seedlings in the screen cages more frequently than seedlings in the tubes. Despite efforts to secure screen cages to the ground, voles were able to get underneath, strip bark, and even completely girdle several seedlings. Similarly, grasshoppers gained access to seedlings in screens after they grew out the tops, and then consumed considerable amounts of foliage. Neither of these animals seriously damaged seedlings in the treeshelters. Because we sunk the tubes several inches into the ground, voles were unable to burrow underneath. The ability of treeshelters to prevent vole damage to oak seedlings has been reported previously (Davies and Pepper 1989). While the grasshoppers ate some foliage that grew over the tops of the tubes, the seedlings were so large by this time that overall damage was minimal. By modifying temperature, humidity, etc. and protecting seedlings from insect and rodent damage, the treeshelters provided a much more favorable environment, resulting in greater growth and survival.

In all three instances where we detected significant interactions, the rankings of protective types within weed treatments were the same—that is, the average survival and height were greater for seedlings in treeshelters than in screen cages for each of the weed-removal treatments. However, the magnitude of the difference varied, causing the interaction. For survival, seedlings in screens and tubes had similar survival under the greatest intensity of weed removal, but much higher survival in treeshelters under lesser intensities. The average 1992 height of seedlings in tubes for weed treatment 3 (1.2-m circles) was more than five times that for seedlings in screens, while for the other three weed treatments, it was only approximately two to three times as great.

There was a general trend for seedlings to grow in proportion to the initial level of weed control. Though the average basal diameter of seedlings from the 1.8-m treatment was only significantly greater than that of seedlings from the 1.2-m treatment in the third growing season, it appeared that both diameter and growth tended to be greater for the larger circles. We therefore do not know how large circles should be to promote maximum growth. It may be that circles even larger than 1.8 m would stimulate even greater growth. However, the benefits of larger circles must be weighed against the costs or difficulty of providing the treatment. In this study, weed control was by hand scalping, which was both difficult and time consuming. The 1.8-m circles took approximately twice as long to scalp as the 1.2-m ones. The gain from such scalping may not be worthwhile.

In such situations, we recommend 1.2-m circles. However, if herbicides are used for weed control, we recommend circles of at least 1.8 m in diameter, because the additional expense and effort would likely be minimal.

As indicated previously, all weed-control treatments were discontinued after the second year. There appeared to be an initial benefit from providing a second year of weed control, not only for survival, but also for height and diameter growth. However, the benefits of this second year of treatment—at least in terms of survival and height—tended to diminish over time, in that the average survival of seedlings from both groups remained relatively constant after the second year, and height increments were similar. Thus, though an additional year of weed control may offer some benefits in field performance, these benefits are likely to be most pronounced during the first 2 years the seedlings are treated differently.

Though it took some time for the weeds to return to the scalped circles, differentiating between treated and untreated areas is difficult today. Both have a thick covering of weeds. Despite this similarity, seedlings in the treated plots continue to grow faster than those from untreated plots. Clearly, these plants obtained an initial advantage from which they continue to benefit. These data suggest that continued weed control is unnecessary for adequate growth and survival once seedlings are established. However, in a slightly older research plot within 100 m of this study area, where weed control has not been maintained, saplings more than 2.5 m tall and 4 cm in diameter have been girdled by voles, and bark has been removed more than a meter up on the stem. We believe that vole populations increased dramatically when we stopped controlling weeds several years ago, and that without protection, the saplings were vulnerable. So while it may not be necessary to continue weed control after 2 years to limit vegetative competition, failure to do so may promote such a favorable habitat for rodents that even large unprotected saplings may be seriously damaged.

## Conclusions

This study indicates that treeshelters can promote substantially greater survival and growth of blue oak seedlings planted on hardwood rangelands in California. Treeshelters appear to protect seedlings from at least two damaging animals and stimulate aboveground growth. We believe this rapid, initial growth is highly beneficial because it can reduce the time needed for seedlings to grow to a size at which they are less vulnerable to browsing pressures. Additionally, intensity of weed control significantly affects performance. Generally, weed-free circles with larger diameters promote higher survival and faster growth. We believe these circles should be a minimum of 1.2 m in diameter. Maintaining weed-free areas around seedlings for two complete growing seasons results in greater survival and growth than treatment for only 1 year. However, it appears that the benefits of this additional treatment tend to subside over time.

## Acknowledgments

We thank the staff at the California Department of Forestry and Fire Protection Lewis A. Moran Reforestation Center for rearing and maintaining the oak seedlings before outplanting. This project was partially funded by a grant from the University of California Sierra Foothill Research and Extension Center.

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