Effects of Cultural Inputs on Survival and Growth of Direct Seeded and Naturally Occurring Valley Oak Seedlings on Hardwood Rangeland[1]

Elizabeth A. Bernhardt[2] Tedmund J. Swiecki[2]

Abstract: *In 1989, acorns were planted at three locations in northern California as part of a project to demonstrate methods for restocking valley oak on hardwood rangeland using site-specific cultural inputs. Inputs used included protective caging, cattle exclusion, mulching, tillage, and first-year irrigation. In 1995, survival ranged from more than 80 percent in the best treatment/site combination to zero in the worst, and maximum seedling height was 288 cm. Protection from cattle was essential for seedling growth and survival in grazed fields. Seedling survival and growth in caged sites was greater in grazed fields than in adjacent nongrazed fields. Landscape fabric and wood chip mulches applied at planting favored seedling growth and/or survival.*

Valley oak, *Quercus lobata* Nee, is frequently included in oak planting projects. This species is relatively easy to propagate, particularly with intensive cultural inputs during the establishment phase. However, intensive inputs may be prohibitively expensive for large-scale plantings intended to restock formerly wooded rangelands. Furthermore, intensive inputs may not be necessary to restock valley oaks in some areas. If large areas of valley oak woodlands are to be restored, land managers will need to identify the set of cultural inputs that will permit them to restock target areas at a minimum of cost.

In 1989, we reviewed the literature and evaluated previous plantings to identify factors that affect the establishment of valley oak seedlings (Swiecki and Bernhardt 1991). Using this information, we designed demonstration projects for three locations in northern California. For each project site, we determined what factors were most likely to limit seedling establishment and growth. We then selected restocking methods for each project which represented varying levels of cultural inputs, starting from the minimum deemed necessary to establish seedlings. The combinations of inputs tested in each planting differ because of the different conditions that existed at each location.

We previously reported on survival and growth at these projects 9 months (Bernhardt and Swiecki 1991) and 18 months after planting (Swiecki and Bernhardt 1991). In this paper, we report on results from these projects after 6 growing seasons. A fourth demonstration project site, at The Nature Conservancy's Cosumnes River Preserve, was included in the original study (Bernhardt and Swiecki 1991, Swiecki and Bernhardt 1991). We do not include follow-up data on the Cosumnes project in this paper, because it differs in many respects from the projects at the other three locations.

Methods

The demonstration plantings are at three sites: the California Academy of Science's Pepperwood Ranch Natural Preserve in the North Coast Ranges of Sonoma County; the Napa County Land Trust's Wantrup Wildlife Sanctuary in

[1]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.

[2]Principals, Phytosphere Research, 1027 Davis Street, Vacaville, CA 95687

Pope Valley; and the City of Vacaville's Hidden Valley Open Space reserve in Solano County. All three locations have been used for livestock grazing for a number of years. Elevations of the three locations are 76 m for Vacaville, 200 m for Wantrup, and 305 m for Pepperwood. Historical average annual rainfall is 64 cm for Vacaville, 76 to 89 cm for Wantrup, and an estimated 102 cm for Pepperwood. A drought reduced rainfall during the first 2 years after planting by 30 to 50 percent, depending on the location. The areas selected for restocking were open, grassy fields that, historically, had supported valley oaks. All fields had at least some scattered valley oaks at their edges or nearby. There was no significant shrub cover within any of the fields. Harding grass (*Phalaris tuberosa* L. var. *stenoptera* [Hack.] Hitchc.) was prevalent at the Pepperwood and Wantrup sites. We have previously reported detailed descriptions of the study sites (Bernhardt and Swiecki 1991, Swiecki and Bernhardt 1991).

At all locations, volunteers planted locally collected acorns in late October or early November 1989. For most treatments, planting sites were prepared by using a shovel to turn over and break up the soil. At each site, four intact acorns were planted on their sides at a depth of about 5 cm, spaced 15 cm apart in a square pattern. At Wantrup, soil was not turned over before planting, and acorns were inserted into cracks in the soil opened up with a shovel.

In grazed fields, we used cages constructed of welded, 5- by 10-cm mesh galvanized 12-gauge wire fencing to protect seedlings from browsing by both cattle and deer (Vaca cages). Each Vaca cage was secured on one side by a steel T-post and on the opposite side by a 86-cm length of 9.5-mm diameter steel reinforcing bar (rebar), which was driven into the soil at least 30 cm. In nongrazed areas, we used cages constructed of lightweight 2.5-cm diameter wire mesh (poultry netting) to prevent deer browsing (deer cages). Deer cages were secured by a 150-cm length of rebar or a T-post on one side and a 60-cm length of rebar on the opposite side. Both Vaca and deer cages were 122 cm tall and about 45 cm in diameter.

We used 90-cm squares of nonwoven polypropylene landscape fabric (Typar®, Reemay, Inc.) as a mulch in some treatments. We cut two slits about 30 cm long in an "X" pattern in the center of each fabric square to permit emergence of oak seedlings and fastened the fabric to the ground with a 10-cm long steel staple in each corner. Because Typar® fabric breaks down when exposed to sunlight, we covered it with a 5- to 7-cm thick layer of waste wood chip mulch, following the manufacturer's recommendations. Other materials used for mulch included a 5- to 7-cm thick layer of waste wood chips and a 7- to 10-cm thick layer of old, moldy oat hay.

We collected data on seedling survival and height several times during the first two growing seasons and annually or less frequently between 1992 and 1995. Survival percentages we report are based on the total number of planting sites in which seedlings emerged during the first year. The overall percentage of sites with emerged seedlings was 81 percent at Pepperwood, 82 percent at Wantrup and 97 percent at Vacaville (Swiecki and Bernhardt 1991). Average heights reported are those of the tallest live seedling at each planting site, and height analyses exclude sites without live seedlings. We used contingency table analysis and logistic regression to analyze the effects of treatments on seedling survival, and analysis of variance to analyze the effects of treatments on seedling heights. Differences and effects reported as significant are significant at $P \leq 0.05$, unless otherwise noted.

Vacaville

The Vacaville project site is an urban open-space buffer between housing developments within the City of Vacaville and consists of two adjacent south-facing hillsides of about 2.8 ha each. Both hillsides are grazed by cattle at variable stocking rates that average about 2.5 animals/ha. Grazing periods have varied as follows:

	Grazing season	
Year	*West hill*	*East hill*
1990	April – mid-May	Late March – late-April
1991	May – mid-July	Mid-March – late-April
1992	December 1991 – late-June	December 1991 – late-June
1993	Mid-March – late-April	No grazing
1994	Early January – late-June	Early April – late-June
1995	December 1994 – late-July	December 1994 – late-June

We anticipated that damage by cattle, moisture stress due to weed competition, soil depth and compaction, and vandalism would be the most likely factors to limit restocking success at this site. To protect seedlings from cattle, we installed Vaca cages on all but a single treatment. We marked noncaged sites with metal tags pinned to the soil with 110-cm nails and used a metal detector and distance and azimuth readings from known reference points to relocate the sites.

We used landscape fabric mulch in two treatments, and the remaining treatments received a thin mulch of dry grass. For one treatment, we used a two-person power soil auger with a 10-cm diameter bit to loosen the soil to a depth of 45 to 60 cm. For two other treatments, we probed the soil at potential planting sites with a 6-mm diameter steel rod in an attempt to differentiate between shallow/compacted sites and deep/noncompacted sites. We combined these cultural inputs to construct the following five planting treatments and planted 30 planting sites per treatment on each hillside:

Treatment	*Cultural inputs*
V1	No cage, grass mulch, probe to depth of 45-60 cm
V2	Vaca cage, grass mulch, probe to depth of 45-60 cm
V3	Vaca cage, grass mulch, probe to depth of 30 cm
V4	Vaca cage, landscape fabric, wood chip mulch
V5	Vaca cage, landscape fabric, wood chip mulch, auger to depth of 45-60 cm

Pepperwood

The planting locations at Pepperwood are two adjacent hillside fields, one currently grazed by cattle and the other nongrazed. For the first several years after planting, cattle had access to the grazed field from late October to mid-May, and there was little residual herbaceous cover at the end of this period. Since 1992, the grazed field has been stocked at 2.5 animals/ha, and grazed for 1 to 3 weeks in late spring or early summer.

We anticipated that browsing by cattle and deer and water stress due to shallow soils and weed competition would be the major factors limiting restocking. We protected all sites with cages, using deer cages in the nongrazed field and Vaca cages in the grazed field.

To cope with the limitation of soil depth and make the best use of available soil moisture, we avoided areas with extremely shallow soil and concentrated our planting sites near seeps and seasonal creeks present in the fields. We planted 40 to 41 sites per treatment in the grazed field, and 24 to 33 sites per treatment in the nongrazed field. The treatments were:

Treatment	*Cultural inputs*
P1	No mulch (both fields)
P2	Wood chip mulch only (both fields)
P3	Landscape fabric mulch (both fields)
P4	Landscape fabric mulch, first summer irrigation (nongrazed field only)

Sites in the irrigated treatment received approximately 40 L of water per irrigation through 4-L/h drip emitters once a month, beginning 1 June 1990 and ending 1 September 1990.

Wantrup

The Wantrup Wildlife Sanctuary planting sites are located in three adjacent fields on the nearly level floor of Pope Valley. Field 1 is a 40.5-ha pasture that has been grazed for many years, and since 1989, it has been stocked with about 15 cow-calf pairs from December through June. There is little residual herbaceous cover after seasonal grazing, except for patches of yellow star thistle (*Centaurea solstitialis* L.). Field 2 is an area adjacent to a seasonal creek which was fenced to exclude cattle in about 1984. Field 3 had been grazed less heavily than field 1 for several years before planting, and grazing was discontinued after planting. Field 3 was tilled in summer 1995, and eight planting sites that had live seedlings in October 1994 were destroyed.

We expected that browsing by deer and/or cattle, moisture stress due to weed competition, damage by ground squirrels in the grazed field, and gophers in field 3 would limit restocking at this location. We used Vaca cages in the grazed field and deer cages in the remaining fields to protect seedlings from browsing. We avoided areas of high rodent activity for most plantings, but some planting sites in field 1 were intentionally located near an active ground squirrel colony for comparative purposes.

We tested several cultural inputs to reduce weed competition and conserve soil moisture. In each field, a strip about 4 m wide was tilled with a disc in September 1989 to remove weeds. We planted sites in both the tilled areas and in adjacent nontilled areas in each field. Every other site was mulched with hay at the time of planting.

In the nontilled portion of field 3, we also tested hay-mulched and nonmulched drip irrigation treatments. During 1990 only, irrigated sites received 20 L of water once weekly, starting 13 May and ending September 17.

We also tested herbicide application as a weed-control treatment in the nontilled portion of field 2. Glyphosate was applied at full label rate in a 150-cm radius around each planting site 1 month before planting and again about 1.5 months after planting. The post-planting application occurred several months before oak seedling emergence. No mulch was used in the herbicide treatment.

We used a 3 by 2 by 2 factorial design for the bulk of the planting: three fields with nontilled/tilled and nonmulched/mulched treatments in each. Irrigated (mulched and nonmulched) and herbicide treatments were treated as three separate treatments in addition to the 12 factorial treatment combinations. We planted 20 sites for each treatment.

At Wantrup, we also set up a separate study in field 1 involving existing natural valley oak seedlings and saplings, all of which were heavily browsed. Initial heights of these oaks ranged from 10 to 52 cm and averaged 35 cm. On 6 June 1989, we set up several types of protective cages around 22 juvenile oaks in the grazed portion of the field and four within a 0.5-ha barbed wire exclosure that excludes cattle but not deer. The cages were originally of varying heights, but all were eventually upgraded to a height of at least 120 cm. Using distance and azimuth measurements to known reference points, we charted the positions of 20 additional oaks in the grazed area and six in the exclosure. These noncaged oaks were located among and were similar in height and condition to the caged oaks. We measured the heights of the caged and noncaged oaks on 6 June 1989 and periodically thereafter.

Results

Seedling Survival

By July 1995, survival at Vacaville was significantly affected only by the use of Vaca cages (*fig. 1*). Survival of noncaged seedlings was significantly lower than that of caged seedlings. The largest single-year decline in survival of noncaged seedlings occurred between the 1991 and 1992 growing seasons. Noncaged sites had few live seedlings after the extended 1992 grazing season. However, some of the browsed-off seedlings resprouted and were observed in 1993, during which one field was grazed lightly and the other was not grazed. Mortality includes four caged sites that have been lost due to vandalism.

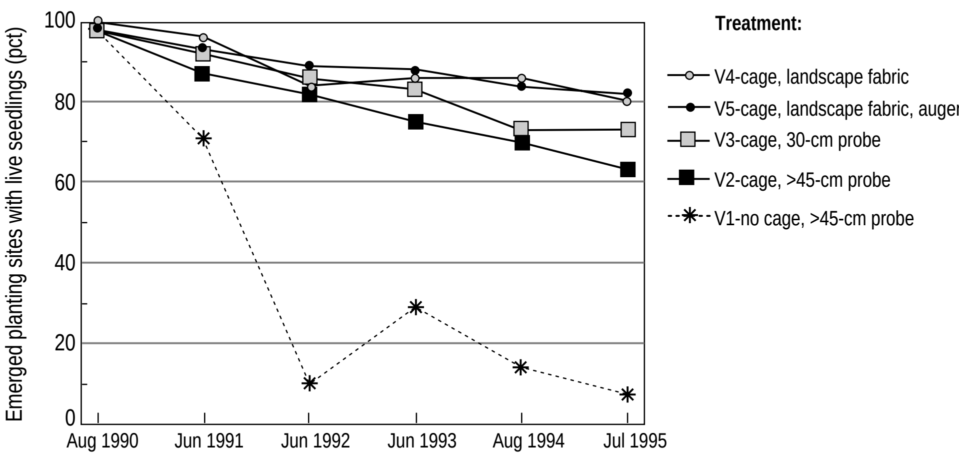


Figure 1—Survival by treatment of planting sites at Vacaville.

At Pepperwood, survival through 1995 (*fig. 2*) was significantly affected by both field and treatment, but the logistic regression analysis showed no significant interaction between these variables. Most treatments showed a sharp drop in survival between June 1991 and June 1992. In 1995, the overall survival rate of caged seedlings in the grazed field (70 percent) was significantly greater than in the nongrazed field (45 percent). Seedling damage attributed mainly to voles has been common in the nongrazed field, which is covered with a very dense and tall (100-180 cm) stand of Harding grass. In the grazed field, cattle have kept growth of Harding grass and other herbaceous weeds in check, and there has been little rodent damage.

Within each field, seedling survival was significantly greater in mulched treatments than in nonmulched treatments (*fig. 2*). First-year irrigation, tested only within the nongrazed field, did not affect seedling survival.

At Wantrup, survival differed significantly between fields (*fig. 3*), but was not affected by mulch, tillage, herbicide, or irrigation treatments. As at the other locations, the greatest increase in seedling mortality occurred between June 1991 and June 1992.

Figure 2—Survival by treatment and planting sites at Pepperwood.

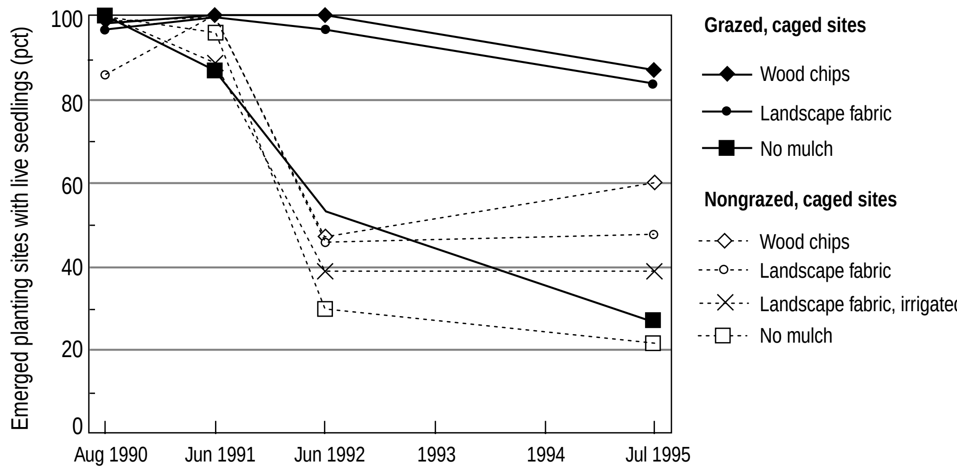
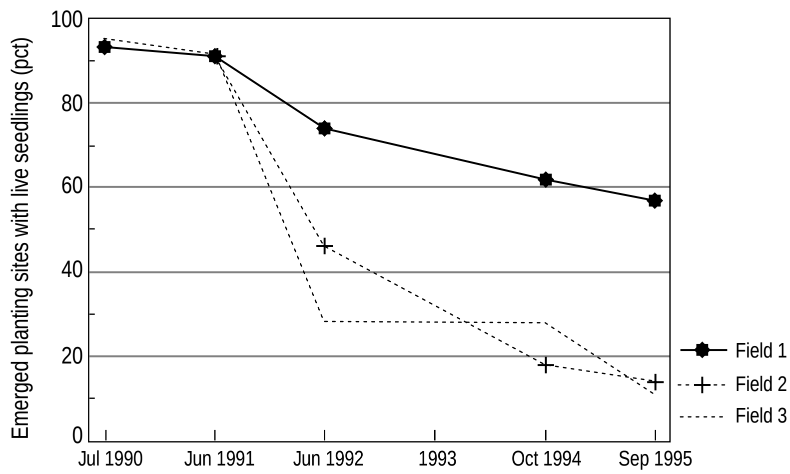


Figure 3—Survival by field of planting sites at Wantrup, where Field 1 = caged, grazed; Field 2 = caged, ungrazed; and Field 3 = caged, ungrazed.



Survival of seedlings in the caged sites in the grazed field (field 1) was greater than that in the nongrazed fields (*fig. 3*) as early as 1992, and this difference was highly significant in 1994 and 1995. By 1995, both nongrazed fields had dense stands of Harding grass, although the Harding grass density in field 3 had been much lower at the start of the project. Seedling damage attributed to voles was common in the nongrazed fields, but rare in the grazed field.

Within the grazed field, seedling survival was significantly lower among sites located within 10 to 15 m of an active ground squirrel colony than among sites located farther away from the colony. By September 1995, 31 percent of the sites near the ground squirrel colony had live seedlings, compared to 65 percent survival for sites away from the colony.

Seedling Growth

In the two-way analysis of variance of 1995 seedling heights for Vacaville, the effects of hillside and treatment were significant, but the interaction between these factors was nonsignificant. Seedlings on the east hillside were significantly taller than those on the west hillside (*fig. 4*). Much of this difference is due to rapid growth in planting sites on the east hillside which are located on an alluvial fan. Valley oaks located in this area were much taller than seedlings on other parts of the hillside and ranged up to 288 cm tall in 1995. In addition, some of the seedlings on the west hillside were defoliated by grasshoppers in mid- to late summer of 1994 and 1995, but such damage has not occurred on the east hillside.

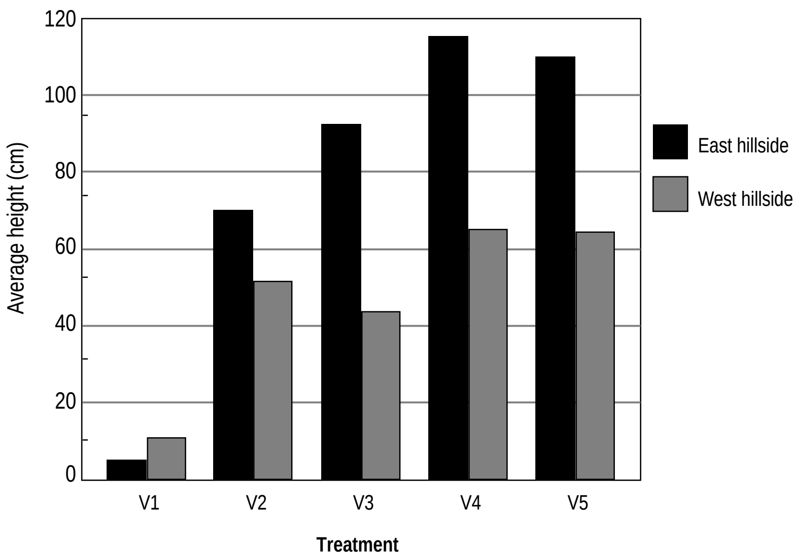


Figure 4—Average height of the tallest surviving seedling per site in July 1995 by treatment and hillside at Vacaville. See text for treatment descriptions.

The few surviving noncaged seedlings were significantly shorter than the seedlings in Vaca cages (*fig. 4*). The average seeding height in the caged sites has increased steadily, whereas the average height of the noncaged seedlings has fallen from 10 cm in 1990 to 6.5 cm in 1995. Based on orthogonal contrasts, seedlings in caged, mulched treatments (V4 and V5) were significantly taller than those in caged, nonmulched treatments (V2 and V3). All of these same factors and comparisons have been significant since the first height evaluation in August 1990.

Since the seedlings were not thinned after planting, surviving planting sites have one to four seedlings. Average seedling height in 1995 was somewhat greater in sites with more than one seedling than in sites with a single seedling. However, the effect of seedling count per site was not significant in the analysis of seedling heights.

At Pepperwood, the average height of caged seedlings was significantly greater in the grazed field (76 cm) than in the nongrazed field (54 cm) in August 1995. This was true whether or not the irrigated treatment (P4), which was present only in the nongrazed field, was included in the two-way analysis of variance by treatment and field. The effect of treatment was not significant in either the two-way analysis or in one-way analysis of variance tests for each field. The lack of significance is due in part to the low numbers of surviving seedlings in several treatments.

At Wantrup, only the effect of field was significant in a three-way analysis of variance comparing the effects of fields, tillage, and mulch on 1994 and 1995 seedling heights. We omitted irrigated and herbicide treatments from these three-way analyses. Surviving seedlings in the grazed field were significantly taller than those in the nongrazed fields:

	Average height of tallest seedlings per site (cm)[1]
Field 1 (grazed)	85 a[2]
Field 2 (nongrazed)	39 b
Field 3 (nongrazed)	31 b

[1]All planting sites protected from deer or cattle by cages.

[2]Means followed by the same letter are not significantly different at $P < 0.05$.

We also examined the effects of the herbicide and irrigation treatments on seedling height using one-way analysis of variance tests on data from individual fields. None of the within-field analyses showed any significant effects of treatment on seedling height. However, the number of surviving seedlings in most of these treatments was very small, so the power of these tests to detect differences was low.

Protected Natural Juvenile Oaks (Wantrup)

Three natural juvenile oaks in this study died; all of these were noncaged. One noncaged oak within the cattle exclosure died, apparently because of girdling by gophers. Two of the 20 noncaged juvenile oaks in the grazed area died over the study period, apparently because of browsing and trampling by cattle.

The average growth of caged and noncaged natural juvenile oaks between June 1989 and September 1995 is shown below:

	Average increase in height (cm)	
	Caged seedlings	*Noncaged seedlings*
Cattle-grazed area	112	0
Cattle exclosure	74	71

Within the grazed field, caged juvenile oaks grew significantly more than noncaged controls. All caged oaks within the grazed area gained height, with increases ranging from 22 to 272 cm. In contrast, seven of the 18 surviving noncaged oaks in the grazed area were shorter in 1995 than they were in 1989, and none of these oaks grew more than 24 cm. Within the cattle exclosure, growth of caged and noncaged juvenile oaks did not differ significantly, even though this exclosure is frequented by deer.

Cage Performance

Vaca cages used at each of the sites have required periodic maintenance, because some of the cages are seriously bent or dislodged by cattle each year. In areas that receive especially heavy use by cattle, we have had to reinforce the cages by adding an additional T-post and/or longer rebar stakes. At Vacaville, several cages are typically removed by vandals each year, but are usually relocated and replaced. Deer cages were effective at Wantrup and Pepperwood and did not require any maintenance.

Discussion

The demonstration projects clearly show that in rangeland seasonally stocked with moderate cattle densities, planting sites must be protected from cattle browsing and trampling in order to successfully restock valley oak. Although first-year emergence did not differ significantly among treatments at Vacaville (Bernhardt and Swiecki 1991), after 6 years, survival and growth is practically nil in the planting sites left unprotected from cattle. Over seven growing seasons at Wantrup, established natural seedlings and saplings grew substantially only if they were protected from cattle. Half of the cattle-exposed oaks in the natural juvenile oak study either lost height or died over this interval.

In grazed areas where sufficient numbers of existing seedlings or saplings can be located, protective caging may be the only input required for restocking. On the basis of the strong results of the demonstration projects, land managers at both Pepperwood and Wantrup have begun to protect individual natural seedlings from browsing to help restock degraded stands. The Vaca cage (Swiecki and Bernhardt 1991) has been fairly successful as a cattle-excluding structure. Vaca cages currently require about $8.00 to $10.00 worth of materials (if purchased new) and are fairly easy to construct, but do require periodic inspection and maintenance. Caging individual seedlings or planting sites is therefore somewhat intensive in terms of materials and labor, but this input is critical for restocking valley oak in cattle-grazed fields.

Cattle can inhibit natural or artificial regeneration by damaging or killing oak seedlings and saplings. However, by controlling the growth of herbaceous vegetation, grazing can indirectly favor growth and survival of caged oak seedlings. At Pepperwood and Wantrup, where all planting sites were individually protected from browsing, survival and growth of seedlings were significantly greater in grazed fields than in adjacent nongrazed fields. At both of these locations, the nongrazed fields are densely populated with Harding grass, which competes with oak seedlings for soil moisture. Various researchers have shown that competing herbaceous vegetation can reduce survival and growth of oak seedlings (Adams and others 1991, Griffin 1971, Knudsen 1987).

Furthermore, the dense Harding grass in the nongrazed fields at Pepperwood and Wantrup also provides habitat for voles and other rodents. Repeated clipping of seedling shoots and leaves by voles (Tecklin 1995), and possibly other small rodents, has apparently contributed to seedling mortality in the nongrazed fields. Moisture stress due to Harding grass competition may further exacerbate damage caused by voles or other agents. Slow-growing, water-stressed seedlings remain susceptible to small herbivores for an extended period and have smaller carbohydrate reserves to draw upon for recovery after being damaged.

Mulch applied at planting is a relatively inexpensive, one-time input that can suppress weed growth and conserve soil moisture around planting sites. At Vacaville and Pepperwood, landscape fabric and/or wood chip mulches were beneficial in promoting seedling growth and survival (*figs. 1, 2,* and *4*). The moldy hay mulch used at Wantrup did not provide any growth or survival benefit and was somewhat inhibitory to seedling emergence (Swiecki and Bernhardt 1991). The hay mulch was originally quite compacted and did not break down well because of low rainfall in the first winter. Within the nongrazed fields, the hay was also used by voles for nesting. Therefore, while mulch can be a beneficial input, improper materials or poor application may negate any potential benefits.

By 6 years after planting, none of the other cultural inputs we used at planting significantly affected either survival or growth, although they did entail additional cost and effort. Irrigation during the first summer, which was an expensive input, did not significantly increase survival or growth of seedlings growing in nongrazed fields at Pepperwood and Wantrup. Based on field observations, these seedlings generally sustained greater damage from small herbivores than did nonirrigated seedlings. Damaging animals may be attracted to irrigated sites by the moist soil or increased succulence of oak tissues.

As expected, seedlings close to the ground squirrel colony at Wantrup had much lower survival rates than seedlings farther from the colony, but gophers have not caused substantial amounts of mortality to date. Our strategy of locating planting sites away from active rodent burrows has been successful in minimizing damage caused by gophers and ground squirrels. This simple step may be sufficient to eliminate the need for more expensive inputs, such as additional caging or shelters, if gopher and ground squirrel populations are not excessive.

At all locations, treatments with less than 60 percent survival by 1995 showed the largest drop in survival between the 1991 and 1992 growing seasons, or 2 years after planting (figs. 1-3). This may represent the point at which carbohydrate reserves derived from the acorn are exhausted in seedlings that die back to the ground early during the first two growing seasons. We previously reported that natural blue oak seedlings that died back to the ground in 2 successive years had higher mortality rates than seedlings that maintained aboveground shoots in one or both years (Swiecki and others 1990).

Although some of the trees in the Vacaville planting have grown well above browse line in 6 years, it will clearly be many years before most of the valley oaks in the demonstration projects are recruited to the tree stage. Overall growth rates for the plantings are fairly low, averaging between about 5 and 15 cm/year for caged seedlings. Even though the plantings were established during a prolonged drought, such low growth rates are probably not atypical for nonirrigated plantings growing under rangeland conditions.

Although some of the trends we observed in the first two growing seasons have persisted into the 6th season, other trends have changed substantially. For example, although the difference in growth between grazed and nongrazed fields was noticeable at Pepperwood the first year after planting, at Wantrup, seedlings in the grazed field were initially shorter than those in field 3 (Swiecki and Bernhardt 1991). The difference in survival now evident between grazed and nongrazed fields at Wantrup and Pepperwood did not develop within the first two seasons. Long-term monitoring of oak planting projects is necessary to determine which cultural inputs are the most worthwhile.

Acknowledgments

The first 2 years of this study were supported by Contract 8CA84965 from the California Department of Forestry and Fire Protection, Forest and Rangeland Resources Assessment Program. We gratefully acknowledge the important roles of land managers Joe Callizo, Wantrup Sanctuary, and Greg DeNevers, Pepperwood Preserve, in the establishment and maintenance of field plots and in data collection.

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