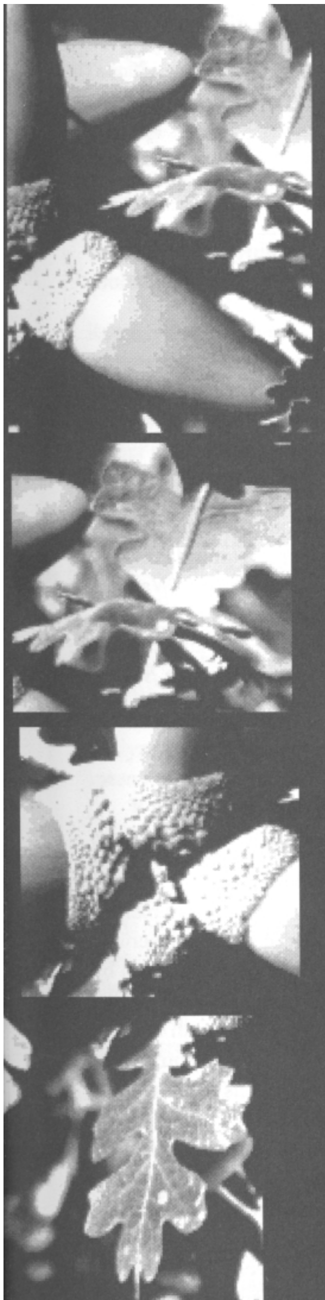

Regeneration & Restoration of Hardwood Rangelands

Minimum Input Techniques for Valley Oak Restocking[1]

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Abstract: We set up experiments at four locations in northern California to demonstrate minimum input techniques for restocking valley oak, *Quercus lobata.* Overall emergence of acorns planted in 1989 ranged from 47 to 61 percent. Use of supplemental irrigation had a significant positive effect on seedling growth at two of three sites. Mulch, of organic materials or polypropylene landscape fabric, significantly increased growth at all four locations. Seedlings enclosed in individual wire cages were effectively protected from browsing by deer or cattle.

The valley oak, *Quercus lobata* Née, has been eliminated from much of its former range in California due to clearing for agricultural and urban development. Furthermore, natural regeneration may be insufficient in many parts of its remaining range to maintain current stand densities (Bolsinger 1988, Muick and Bartolome 1987). Artificial regeneration is therefore necessary to restore many stands that have been lost or degraded. Effective, low-cost restocking techniques are needed if significant areas of valley oak woodlands are to be restored.

To gain insight into the influence of restocking techniques on survival of valley oak in restocking projects, we visited and evaluated a number of valley oak restoration projects throughout California that were undertaken in the past 10 years. Overall, water deficit and vertebrate damage were the most important factors affecting seedling survival at the sites we evaluated (Swiecki and Bernhardt 1989). These factors are also the most commonly cited constraints to seedling establishment reported in the literature (Danielsen 1990, Griffin 1971, Gordon and others 1989, Knudsen 1987, Rossi 1980). We incorporated information from our review of these past restoration projects and from the literature into a conceptual model that indicates the types of inputs required to obtain successful seedling establishment under different site conditions (Swiecki and Bernhardt 1989).

In1989, we established a number of demonstration projects designed to test the assumptions of our conceptual restoration model. The projects are located at four sites in northern California. Valley oaks are present in the vicinity of all project sites, but are almost completely lacking within the areas selected for restocking. Restocking methods selected for each project were tailored to the site conditions and represented varying levels of cultural inputs, starting from the minimum deemed necessary to establish seedlings.

This paper reports the results of restocking techniques for the first season at all sites and the second season in one location.

METHODS

We set up demonstration projects at four sites: the California Academy of Sciences' Pepperwood Ranch Natural Preserve in Sonoma County; the Napa County Land Trust's Wantrup Wildlife Sanctuary in Napa County; The Nature Conservancy's Cosumnes River Preserve in Sacramento County; and the City Vacaville's Hidden Valley Open Space reserve in Solano County.

General Methods

At all locations, locally-collected acorns were used and. volunteers assisted with the plantings. The Cosumnes site was planted in December of 1988. All other locations were planted from late October through early November of 1989 as described below. For most treatments, planting sites were prepared by turning over and breaking up the soil with a shovel. 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 prior to planting, and acorns were inserted into cracks in the soil opened up with a shovel.

At all locations except Cosumnes, individual seedlings were protected from browsing by deer or cattle with one of two types of protective cages, both of which were 122 cm tall and about 45 cm in diameter. The cages were made of readily available materials and designed to minimize costs of materials and installation. Individual exclosures to protect seedlings from browsing by both cattle and deer (Vaca cages) were constructed of welded 2 by 4 in mesh galvanized 12 gauge wire fencing. Each cage was secured on one side to a T-post and on the opposite side by a 86 cm length of steel reinforcing bar (rebar) which was driven into the soil at least 30 cm. Cages to prevent deer browsing (deer cages) were not designed to withstand cattle and were only used in nongrazed areas. They were constructed of lightweight I in diameter wire mesh (poultry netting). Deer cages were secured to a 150 cm length of rebar or a T-post on one side and a 60 cm length of rebar on the opposite side. Relative costs of the materials and approximate times required for exclosure construction are shown in table 1.

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Table 1—*Cost (1989) and labor estimates for components of some treatments.*

(Treatment	Materials cost	Assembly time	Installation time/site
Vaca cage	$5.36	5-6 min	5-7 min
Deer cage	$2.92	4-5 min	3-4 min
Landscape fabric	$1.04	1-2 min	1-2 min
Drip irrigation[1]	$174.30	—	—

[1]1000 ft drip line, emitters, an fittings for 50 sites.

Nonwoven polypropylene landscape fabric (Typar®, Reemay, Inc.) was used to mulch sites in some treatments. The material was cut in 90 cm squares, and two slits about 30 cm long were cut in a "X" pattern in the center of each square. The fabric was fastened to the ground with a 10 cm long steel staple in each corner after the acorns were planted. The Typar® fabric, which breaks down when exposed to ultraviolet light, was covered with 5-7 cm of wood chip mulch following the manufacturer's recommendation.

Data on seedling emergence, condition, and height were recorded periodically for each location. Unless otherwise noted, height and survival data presented here were collected between 15 August and 27 August 1990, and emergence data is cumulative to this period. Mean height of all seedlings and mean height of the tallest seedling for each planting site were calculated and analyzed. In all cases, results for both were similar, and only mean heights of the tallest seedling are reported.

We analyzed the effects of treatments on emergence and condition frequencies using contingency tables and categorical data modeling procedures. Heights were analyzed using analysis of variance. Mean separation in preplanned comparisons was made using least significant difference following a significant F ratio. Where experimental designs became unbalanced due to missing data, least square means (SAS Institute, Inc. 1988) were used. Single degree-of-freedom contrasts were also used to test for differences between selected treatments. The significance level of differences and effects referred to as significant is $P < 0.05$.

Vacaville

The Vacaville location was chosen as the more favorable of two available planting locations on city-owned land. It is an urban open space buffer between housing developments, and consists of two adjacent south-facing hillsides of about 7 acres each. A remnant oak woodland which includes valley oak and interior live oak (*Q. wislizenii* A. DC.) is present on the top of the easternmost hillside. Herbaceous vegetation is largely annual grasses and forbs, but substantial populations of purple needlegrass (*Stipa pulchra* Hitchc.) are spread across both hillsides. Short duration grazing was used in the spring of 1990 for fire suppression. The east hillside was grazed from 28 March to about 23 April at a density of one head per acre. Cattle from an adjoining field were allowed access to the western hillside from 1 April to about 15 May. Soil is a clay loam averaging 75-100 cm deep. We detected subsurface compaction in various spots across both hillsides and exposed rock is visible near the crest of both hills.

At the start of the project 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. Vaca cages were installed on all but a single treatment to protect seedlings from cattle. Landscape fabric mulch was used on two treatments to reduce weed competition and conserve soil moisture. A thin mulch of dry grass was used in the remaining treatments. Two different methods were used to compensate for soil compaction. In one treatment, a two-person power soil auger with a 10 cm diameter bit was used 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 more and less favorable microsites. Sites where the probe could be inserted to a depth of 45 to 60 cm were assigned to the "deep probe" treatment, and sites where the probe could be inserted no more than 30 cm were assigned to the "shallow probe" treatment.

Overall, 5 treatments were tested in this location, with 30 planting sites per treatment on each hillside. The treatments were:

V1. No protection, grass mulch, sites prepared only with a hand trowel at planting.

V2. Vaca cage, grass mulch, deep probe sites.

V3. Vaca cage, grass mulch, shallow probe sites.

V4. Vaca cage, landscape fabric mulch, nonaugered sites.

V5. Vaca cage, landscape fabric mulch, augered sites.

Pepperwood

The Pepperwood Ranch Natural Preserve is located in the North Coast Ranges between Santa Rosa and Calistoga. The planting locations are two adjacent fields, one currently grazed by cattle and the other nongrazed. A few mature valley oaks are present around the edges of the nongrazed field. 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. The nongrazed field has a heavy weed cover, with high populations of Harding grass (*Phalaris tuberosa* L. var. *stenoptera* [Hack.] Hitchc.), although other weeds and native grasses including *Stipa pulchra* are also present. The topography of both fields is very uneven and soil depth is variable, with areas where the underlying bedrock is exposed or very close to the surface. Soil texture is a clay loam. Wet seeps and seasonal creekbeds are present in parts of the fields.

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. To avoid the limitation of soil depth and make the best use of available soil moisture, we concentrated our planting sites along the seeps and creekbanks, and avoided areas with extremely shallow soil. We tested both landscape fabric and wood chip mulches for weed control and moisture conservation. An irrigated treatment was also tested in the nongrazed field. Sites were irrigates once a month, beginping 1 June and ending 1 Sept. Each plant received approximately 40 L of water per irrigation through 4 L/h drip emitters. All sites in the nongrazed field were protected with deer cages and those in the grazed field were protected with Vaca cages.

We planted 40 sites per treatment in the grazed field, and 24 to 33 sites per treatment in the nongrazed field. The treatments were:

P1. No mulch (both fields).

P2. Wood chip mulch (both fields).

P3. Landscape fabric mulch (both fields).

P4. Landscape fabric mulch, irrigated (nongrazed field only).

Wantrup

The Wantrup Wildlife Sanctuary planting sites are located on the nearly level floor of the Pope Valley. Large valley oaks are widely scattered across the valley floor and a higher density of mature oaks is found along a seasonal creek channel that crosses through the planting site. Soil averages 30 cm of silty loam overlying silty clay loam to a depth of 150 cm or more. We planted in three adjacent fields. Field 1 has been grazed heavily for many years, and is currently grazed from December through June. There is little residual herbaceous cover after seasonal grazing. Field 2 is an area surrounding the seasonal creek, which was fenced to exclude cattle about 5 years earlier. Weed cover is very dense and includes heavy stands of Harding grass and yellow star thistle (*Centaurea solstitialis* L.). Field 3 had been grazed less heavily than field 1 in previous years, and was not grazed at all in 1990. The weed cover is intermediate between fields 1 and 2, and is dominated by Harding grass.

Browsing by deer and/or cattle, moisture stress due to weed competition, and damage by rodents were the factors which we anticipated would limit restocking at this location. Vaca cages were used in the grazed field and deer cages in the remaining fields to protect seedlings from browsing. Most planting sites were chosen to avoid areas of high rodent activity, although some planting sites in field 1 were intentionally located in close proximity to an active ground squirrel colony for comparative purposes. Several methods of weed control were also tested. In each field, a strip about 4 m wide was tilled in September 1989 with a tractor-mounted disc to remove weeds. Sites were planted in the tilled areas and in adjacent nontilled areas in each field. Planting sites were alternately mulched with moldy hay at planting or left nonmulched. For one treatment in the nontilled portion of field 2, applications of glyphosate (Roundup®) were made 1 month prior to planting and again in the winter 1 to 2 months after planting for weed control. The herbicide was applied in a 150 cm radius around the planting site, avoiding the area immediately adjacent to the planting site in the postplanting application. A drip irrigation treatment was also tested in the untilled portion of field 3. Plants were irrigated once weekly with 20 L of water per site, starting 13 May 1990.

The basic planting was set up as a 3 by 2 by 2 factorial: three fields with nontilled/tilled and nonmulched/mulched treatments in each. Twenty sites were planted for each treatment. The three treatments tested in addition to the 12 treatment combinations from the factorial design were:

WI 3. Field 2, nontilled, nonmulched, herbicide.

W14. Field 3, nontilled, nonmulched, irrigated.

W15. Field 3, nontilled, mulched, irrigated.

Heavily-browsed natural valley oak seedlings and saplings were located in some parts of field 1. On 6 June 1989, we set up several types of protective cages around 26 of these seedlings and saplings. An additional 27 unprotected valley oak seedlings and saplings were paired with nearby protected plants of similar height and condition. Four protected and six unprotected saplings were located within an area bounded by a 120 cm tall barbed wire fence that excluded cattle but not deer. Heights of all seedlings and saplings were measured at the start of the experiment and remeasured on 21 August 1990.

Cosumnes

The Cosumnes River Preserve is on level ground in the Sacramento Valley. We set up two experiments in a 4 acre field which had been cleared and leveled long before acquisition by The Nature Conservancy. The field is bordered by a slough with a narrow band of existing valley oak riparian forest and is infrequently flooded in the winter. The soil is a poorly drained sandy clay loam underlain by calcareous clay and a hardpan at varying depths throughout the field. Herbaceous vegetation varies throughout the field, but is generally dominated by a variety of introduced winter and summer annual grasses and forbs.

An ongoing program of valley oak restocking has been underway at the preserve, and our experimental sites were planted by Conservancy volunteers according to the standard procedures at the preserve. Planting sites were prepared by scraping all vegetation off the soil surface in a 0.5 m radius circle. Two acorns were planted at each site within a 12 cm diameter plastic collar that extended approximately 12 cm below ground. A cylinder of aluminum window screen extending about 30 cm above ground level and folded closed at the top was attached to the top of the plastic collar (Bush and Thompson 1989), and served as the only protection against vertebrates. The screen cages were opened on top when seedlings shoots reached the tops of the cages. Planting sites are arranged on a regular grid and spaced about 3 to 4 m apart.

Since plantings were already in place at the start of our project, we limited our treatments to modifications of the Preserve's currently used post-planting inputs. Sites are routinely irrigated biweekly from the beginning of June through the end of August via drip irrigation with approximately 32 L applied per irrigation. Our experimental treatments included the reduction of irrigation frequency from biweekly to monthly, foregoing irrigation entirely, and using a mulch around the planting site for weed control and moisture conservation.

In plot 1, on the southern end of the field, a 2 by 2 factorial design was employed to test effects of irrigation frequency (2 or 4 week) and mulching, with 53 to 55 sites per treatment. Hay mulch was applied to mulched treatments on 31 May 1989. On the northern portion of the field (plot 2), alternate rows received the standard biweekly irrigation (67 sites) or were not irrigated (79 sites). All irrigated treatments received their first irrigation on 2 June 1989. Planting sites where seedlings were already dead or had not emerged by 31 May 1989, were excluded from the experiments. Some sites were lost in 1990 when a fire break was plowed along one side of the planting. Height data was recorded every 2 weeks throughout the irrigation season in 1989 and 1990, and heights at the end of the first season were recorded 21 November 1989.

RESULTS

Seedling Emergence

At Vacaville, overall, 61 percent of planted acorns produced seedlings. The percent of sites with at least one emerged seedling did not differ significantly between treatments or fields, and ranged between treatments from 89 to 100 percent. When monitoring the planting in the spring of 1990, we found that the landscape fabric was misaligned at many of the sites. To ensure seedling emergence, we enlarged the slits in the fabric or repositioned shoots that were trapped under the fabric. Had this not been done, overall emergence in the fabric mulched sites would have been decreased.

At Pepperwood, 47 percent of the planted acorns produced seedlings. Emergence by planting site was significantly higher overall in the grazed field (89 percent) than in the nongrazed field (74 percent). Emergence by site was greatest overall in the wood chip mulch treatment (96 percent) and lowest overall in the nonmulched treatment (73 percent). While rates of emergence for these treatments were similar in both fields, emergence through the landscape fabric mulch was much lower in the nongrazed field (58 percent of sites) than in the grazed field (95 percent of sites).

At Wantrup, 53 percent of the planted acorns produced seedlings. There were no significant differences in emergence between the three fields. A significantly higher percentage of nonmulched sites (87 percent) had emerged seedlings than did mulched sites (77 percent). Emergence was also higher in sites that had been tilled (92 percent) than in the nontilled sites (71 percent).

Seedling Growth

At Vacaville, average heights of the tallest seedling at each site differed significantly between treatments and hillsides in the 2-way analysis of variance. Even though cattle were on the fields at Vacaville for only 4 to 6 weeks, the average height of unprotected seedlings was significantly less than that of protected seedlings (below). There was no significant difference in height between seedlings in deep probe and shallow probe sites, or between those in augered and nonaugered sites. Among seedlings protected from cattle browsing, those mulched with fabric were significantly taller than nonmulched seedlings. Average seedling heights for all treatments were as follows:

Treatment	Average seedling height (cm) East hill	West hill
V1. No protection	12	8
V2. Vaca cage, deep probe	17	16
V3. Vaca cage, shallow probe	18	14
V4. Vaca cage, fabric mulch, nonaugered	24	20
V5. Vaca cage, fabric mulch, augered	21	23

The irrigated treatment (P4) was not included in the 2-way analysis of variance for Pepperwood, since it was not replicated in both fields. In the 2-way analysis, average seedling heights were significantly greater in the grazed field than in the nongrazed field, and nonmulched seedlings were significantly shorter than those in either of the mulched treatments:

Treatment	Average seedling height (cm) Nongrazed	Grazed
P1. No mulch	8	9
P2. Chip mulch	10	13
P3. Landscape fabric	10	12
P4. Irrigated	11	—

In the 1-way analysis of variance for treatments in the nongrazed field, which included the irrigated treatment, there was no significant treatment effect on seedling height.

At Wantrup, average heights of the tallest seedling ranged from 8 cm in the nonmulched, nontilled treatment in field 1, to 16.5 cm in the irrigated, mulched treatment in field 3. Seedling heights in the irrigated treatments did not differ significantly from those in nonirrigated mulched treatments in the 1-way analysis of variance of all treatments. Seedling heights in the herbicide treatment were near the overall average for all treatments.

We conducted a 2-way analysis of variance of the data from field 3, with mulching and 'method' (nontilled/nonirrigated, tilled/nonirrigated, and nontilled/irrigated) as the main effects. Both mulching and `method' were significant in the analysis of variance, but the interaction term was not. Mulched seedlings were significantly taller than nonmulched seedlings, and irrigated seedlings were significantly taller than those in the other two 'methods'.

Irrigated and herbicide treatments were omitted from the 3-way analysis of variance comparing the effects of fields, tillage, and mulching. In the full interaction model, only fields and mulching significantly affected seedling height. Overall least square means of mulched seedling heights were 12 cm compared to 10 cm for nonmulched seedlings. Seedlings growing in field 3 were significantly taller (12 cm) than those in field 1 (10 cm).

Established natural seedlings and saplings at Wantrup that were protected from grazing grew significantly more than those left unprotected:

Average height change (cm) from 6 June 89 to 21 Aug 90	Protected seedlings	Unprotected seedlings
Area grazed by cattle and deer	+24	-5
Area grazed by deer only	+27	+2

Although deer were highly effective at suppressing height growth, saplings browsed only by deer did not exhibit net height decreases, as was common in the saplings exposed to cattle.

By August of the first growing season (1989), seedlings in mulched sites were significantly taller than those in nonmulched sites at Cosumnes Plot 1, but the effect of irrigation frequency was nonsignificant (table 2). Due to the amount of deer browsing that occurred in the plot in 1990, we analyzed the maximum seedling height recorded during the season rather than the final heights recorded in August 1990. In this analysis, effects of both irrigation frequency and mulch on total height were significant (Table 2). We analyzed second season growth with analysis of covariance, using height in November 1989 as the covariate to correct for the influence of initial height on second-season growth. In this analysis, the differences between maximum height in 1990 and height in November 1989 did not vary significantly with treatment, although the effect of initial height was highly significant.

In plot 2, there was no effect of irrigation on height the first summer but a significant increase in height with irrigation the second summer. The large increase in height with irrigation evident the second year (table 2) was at least partially due to increased shoot survival in the irrigated seedlings. Since many of the nonirrigated seedlings were resprouts, their shoots were shorter than those in the irrigated treatment which were able to make continued growth from the previous year's stems. The average soil depth to hardpan was shallower in plot 2 than in plot 1, and irrigated seedlings in plot 2 were considerably shorter than seedlings in plot 1 which received the same amount of irrigation (table 2).

Table 2—*Average height (cm) and percent of valley oak seedlings browsed at Cosumnes Franklin Plots 1 and 2.*

Treatment	Height 9 22 Aug 8	Max Height 21 Aug 90	Pct browsed
Plot 1:			
Mulched, 2 week irrig	36	62	71
No mulch, 2 week irrig	27	49	53
Mulched, 4 week irrig	33	55	63
No mulch, 4 week irrig	24	39	37
Plot 2:			
No mulch, 2 week irrig	16	31	22
No mulch, no irrig	14	19	3

Seedling Condition

Vaca cages and deer cages installed at Vacaville, Pepperwood, and Wantrup effectively prevented browsing of seedlings by large herbivores. Deer cages in the nongrazed areas were unmolested, but some of the Vaca cages were damaged by cattle. The most common damage was denting of the wire cylinder, which did not usually impair the cage's function. At Wantrup, light weight vineyard posts were used in place of T-posts, and 11 percent were bent by cattle. In other locations, T-posts were sometimes tilted when pushed by cattle when the soil was wet (7.6 percent at Pepperwood, 0.8 percent at Vacaville). Fourteen gauge wire mesh Vaca cages used at Wantrup were also more seriously bent than the 12 gauge cages used at Vacaville and Pepperwood. Rarely, cattle were able to completely dislodge the protective cage. Two cages (0.8 percent) were removed by vandals at Vacaville, but were located and replaced.

At Vacaville, overall 79 percent of the seedlings which emerged were still green on 27 August 1990. Browsing damage to seedlings was visible in 26 percent of the uncaged (VI) sites and in 1 percent of the protected sites. Only 3 percent of the sites showed evidence of rodent digging and seedlings in 5 percent of the sites showed foliar damage from chewing insects.

At Pepperwood, 97 percent of the seedlings were still green on 24 August 1990. Seedlings in 13 percent of the sites showed evidence of having been browsed, presumably by gophers, mice, or voles. There was significantly more browsing in the nongrazed field than in the grazed field, and browsing was most common in the chip mulch treatment (P2). Only 4 percent of the sites showed evidence of rodent digging and 4 percent of the sites showed foliar damage from chewing insects.

At Wantrup, the percentage of green seedlings in all treatments dropped from 87 percent on 1 July to 50 percent on 1 August, and to 22 percent by 21 August 1990. This decrease was not due solely to lack of moisture, because shoot survival in the irrigated treatment dropped from 72 percent on August 1 to 27 percent by August 21. Stem girdling caused by either small rodents or insects was apparently the cause of at least some of the observed shoot mortality. Within field 3, seedlings at 96 percent of the irrigated sites were girdled, whereas seedlings at 54 percent of the nontilled sites and 32 percent of the tilled sites showed similar damage. This symptom was not observed in field 1. Overall, 6 percent of the sites showed foliar insect chewing damage.

Although seedlings in only 0.8 percent of the sites were browsed, 14 percent of sites were disturbed by rodent digging. Eighty-three percent of all disturbed sites occurred in field 1 near the active ground squirrel colony. In this field, rodent digging was significantly more common in the nonmulched sites (58 percent) than in the mulched sites (30 percent). In field 1, 76 percent of undisturbed sites but only 31 percent of the disturbed sites contained seedlings with live shoots by 21 August.

At Cosumnes plot 1, seedlings in only 3 sites (1.4 percent) had died by 21 August 1990. In plot 2,4 percent of the plants in the irrigated treatment, but 43 percent of the plants in the nonirrigated treatment, died during the first summer and did not resprout in 1990. Thirty-seven percent of those seedlings in the nonirrigated treatment whose shoots died the first season resprouted from the crown in 1990. In plot 2 in 1990, 39 percent of the nonirrigated seedlings, but only 2 percent the irrigated seedlings were resprouts. The seedlings at Cosumnes were not protected from deer once they grew beyond the screen cages. The frequency of browsing damage during the summer of 1990 increased with increasing seedling height (table 2).

DISCUSSION

Choosing methods for planting valley oaks in rangeland situations involves trading off the costs of cultural inputs with desired and expected survival and growth rates. The increase in growth and survival that may be obtained with high levels of cultural inputs must be balanced against the additional cost and effort expended. Furthermore, cultural inputs may have unexpected negative consequences as well as positive effects, and the balance between positive and negative effects may vary from site to site. Finally, if the limiting factors at the planting site are not adequately characterized, cultural inputs may overcome one set of limiting factors only to have growth and survival limited by other factors.

Although caging individual planting sites is relatively expensive in terms of materials and labor, our data and previous reports (Griffin 1971, Rossi 1980) indicate that protection from browsing is necessary where restocking is to occur in areas grazed heavily by either cattle or deer. Where existing seedlings or saplings can be located, such as at Wantrup, caging to protect against deer and cattle may be the only input required for restocking. Furthermore, overall costs can be reduced if cages are removed and reused after trees have grown above the browse line.

In our experience, protecting seedlings with either Vaca or deer cages has not been associated with any obvious negative effects. However, Vaca cages may require maintenance, since they can be damaged by cattle. It may be possible to reduce or eliminate maintenance requirements by using higher grade materials. For example, substituting a second T-post for the rebar stake would substantially increase the strength of the cage, but would require a higher initial investment in materials and labor. Damage to Vaca cages was lowest at Vacaville, where the period of grazing was relatively short, indicating that damage may increase with the intensity or duration of grazing. Thus, the grazing pattern should also be considered when weighing the costs and benefits of different cage designs and materials.

The necessity of protecting against damage by rodents to obtain adequate restocking is less certain. The impact of rodent herbivory on seedling establishment and growth are highly variable from location to location. For example, while Griffin (1980) reported extensive seedling destruction by gophers in the Carmel Valley, others (Knudsen 1987, Bush and Thompson 1989) found that seedling losses due to gophers were relatively minor. Knudsen (1987) blamed mice and voles for seedling and acorn losses of valley oak. An unprotected planting of valley oaks was completely destroyed by ground squirrels within weeks in a heavily-infested area in Cheseboro Canyon, whereas 60 to 100 percent of the protected seedlings in the same area survived the first year (Pancheco 1987).

In our sites, damage by rodents was insignificant at Vacaville and the nongrazed field at Pepperwood, despite a complete lack of protection against rodents. In contrast, rodent damage, primarily caused by ground squirrels, significantly reduced shoot survival in field 1 at Wantrup. However, since severe rodent damage was localized near an obviously active colony, reasonable control of rodent damage could be obtained at this location by simply avoiding the most heavily colonized portions of the field. The cup and screen planting method, which was used at Cosumnes, was developed in part to protect seedlings from herbivory by rodents and insects. However, due to the variable nature of rodent damage, and the low overall incidence of insect damage, this particular input is probably unnecessary in many locations. Furthermore, in favorable sites, screens must be opened within the first growing season to accommodate seedling growth. Considering the labor required for installation and follow-up maintenance, the relatively short period of protection provided, and the need for supplemental protection in areas grazed by cattle or deer, the usefulness of this technique for valley oak restocking may be limited to rather specific situations.

Competition for soil moisture may be an important factor limiting natural regeneration in many areas. Introduced Mediterranean annual grasses and forbs have largely replaced native perennial bunchgrasses in the oak understory (Gordon and others 1989). There is experimental evidence to support the widely-held belief that introduced annual grasses and taprooted forbs deplete soil moisture more rapidly than native perennial grasses (Danielsen 1990, Gordon and others 1989). Knudsen (1987) noted that survival of natural valley oak seedlings increased as grass density decreased. Griffin (1971) obtained 100 percent seedling establishment from valley oak acorns planted in cleared plots during a drought year (1967-68), while all seedlings died by May in adjacent grassy plots.

Methods to conserve soil moisture include mulching and weed control. Both the synthetic and organic mulches we used significantly increased seedling height at every location, and data from Cosumnes showed a clear benefit of mulching even among irrigated sites. Mulch not only conserves soil moisture but also serves to moderate soil temperatures (Brady 1974), which may have a beneficial effect on root growth. At Pepperwood, wood chip mulch was as effective as landscape fabric in promoting emergence and growth, and may be the preferred treatment because of the lower input required.

Irrigation is commonly used to augment soil moisture. However, the relatively high cost of materials (table 1) and labor associated with this input generally limits its use in extensive restocking of rangelands. Although irrigation increased seedling growth at Cosumnes and Wantrup, it had no significant effect on seedling height in the first season at Pepperwood. Furthermore, shoot survival at Wantrup was not significantly better in the irrigated treatment than in several of the nonirrigated mulched treatments. Continued monitoring of long-term growth and survival is necessary to determine the relative effectiveness of moisture conservation versus augmentation. However, we were able to successfully establish moderate to high percentages of oak seedlings without irrigation in several locations in the third year of drought conditions.

Several cultural inputs showed unexpected negative consequences. At Wantrup, irrigated seedlings suffered more chewing damage to their stems than did nonirrigated seedlings, resulting in decreased shoot survival rates. Although mulch increased seedling growth, some mulched treatments showed lower rates of seedling emergence. At the Vacaville site, we found that the installation method we used frequently resulted in faulty alignment of the slits in the landscape fabric relative to the emerging seedlings. We expect that this problem may also have contributed to the low emergence at sites mulched with landscape fabric in the grazed field at Pepperwood. The hay mulch used at Wantrup may also have acted as a barrier to seedling emergence.

In some cases, cultural inputs may overcome one set of limitations only to have growth and survival limited by other factors. For example, at Cosumnes, irrigation is being used to accelerate plant growth by alleviating soil moisture limitations. As a result, browsing by deer may now be the most important factor limiting plant growth. Data collected during 1990 showed that the deer most frequently browsed taller seedlings (table 2). We believe that the lack of significant treatment effects on growth from November 1989 to August 1990 may in large part be due to deer browsing of the most vigorous seedlings. Due to the high planting density at this site, some seedlings may be able to escape deer browsing long enough to get above the browse line. However, in areas with high deer populations and low tree densities, even frequent irrigation may not accelerate plant growth enough to offset deer browsing impacts.

The effects of the treatments presented here are known only for the first 1 to 2 seasons after planting. However, it does appear that valley oaks can be restocked using low input techniques tailored to overcome site limitations. Continued monitoring of the plantings will be necessary to determine if treatment effects persist or become damped out as seedlings become more established. Results from previous projects (Swiecki and Bernhardt 1990) indicate that long-term survival may bear little relation to first year survival. With longer-term survival data, the cost-effectiveness of the different inputs could be calculated on the basis of the cost in materials and labor per each successful seedling.

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REFERENCES

Bolsinger, C. 1988. The hardwoods of California's timberlands, woodlands, and savannas. Resource Bull. PNW-RB-148. Portland, OR: Pacific Northwest Research Stn., Forest Service, U.S. Department of Agriculture; 148 p.

Brady, N. C. 1974. The nature and properties of soil. New York: Macmillan Publ. Co. 639 p.

Bush, L.; Thompson, B. 1989. Acorn to oak. Circuit Rider Productions, Inc. Windsor, CA 36 p.

Danielsen, K. C. 1990. Seedling growth rates of *Quercus lobata* Née (valley oak) and the competitive effects of selected grass species. Los Angeles, CA: California State University. M.S. Thesis.

Gordon, D. R.; Welker, J. M.; Menke, J. W.; Rice, K. J. 1989. Competition for soil water between annual plants and blue oak (*Quercus douglasii*) seedlings. Oecologia 79:533-541.

Griffin, J. R. 1971. Oak regeneration in the upper Carmel Valley, California. Ecology 52:862-868.

Griffin, J. R. 1980. Animal damage to valley oak acorns and seedlings, Carmel Valley, California. In: Plumb, T. R., tech. coord. Proceedings of the symposium on the ecology, management, and utilization of California oaks; June 26-28,1979, Claremont, CA. Gen. Tech. Rep. PSW-44. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station., Forest Service, U. S. Department of Agriculture; 242-245.

Knudsen, M. D. 1987. Life history aspects of *Quercus lobata* in a riparian community, Sacramento Valley, California. In: Plumb, T. R. and Pillsbury, N. H., tech. coord. Proceedings of the symposium on Multiple-Use Management of California's Hardwood Resources; Nov. 12-14, 1986, San Luis Obispo, CA. Gen. Tech. Rep. PSW-100. Berkeley, CA: Pacific Southwest Forest and Range Exp. Stn., Forest Service, U. S. Department of Agriculture; 38-46.

Muick, P. C.; Bartolome, J. R. 1987. An assessment of natural regeneration of oaks in California. Department of Forestry and Resource Management, University of California, Berkeley. Prepared for: Calif. Dept. of Forestry, Sacramento, CA; 101 p.

Pancheco, A. A. 1987. Some implications of public involvement in hardwood management. In: Plumb, T. R. and Pillsbury, N. H., tech. coord. Proceedings of the symposium on Multiple-Use Management of California's Hardwood Resources; Nov. 12-14, 1986, San Luis Obispo, CA. Gen. Tech. Rep. PSW-100. Berkeley, CA: Pacific Southwest Forest and Range Exp. Stn., Forest Service, U. S. Department of Agriculture; 144-147.

Rossi, R. S. 1980. History of cultural influences on the distribution and reproduction of oaks in California. In: Plumb, T. R., tech. coord. Proceedings of the symposium on the ecology, management, and utilization of California oaks; June 26-28, 1979, Claremont, CA. Gen. Tech. Rep. PSW-44. Berkeley, CA: Pacific Southwest Forest and Range Exp. Stn., Forest Service, U. S. Department of Agriculture; 7-18.

SAS Institute Inc. 1988. SAS/STAT user's guide, release 6.03 edition. Cary, NC: SAS Institute Inc.; 1028 p.

Swiecki, T. J.; Bernhardt, E. A. 1990. Minimum input techniques for restoring valley oaks on hardwood rangeland: overview and preliminary model. Sacramento, CA: Forest and Rangeland Resources Assessment Program, California Department of Forestry and Fire Protection. 94 p.