Oak Seedling Establishment by Artificial Regeneration on California Rangelands[1]

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Abstract: *Blue oak (*Quercus douglasii *H. & A.) and valley oak (*Q. lobata *Née) seedling establishment on California rangelands is poor in many locations. Research on artificial regeneration is documenting that weed competition and small mammal and insect herbivory can contribute substantially to mortality where large herbivores are excluded. Success of natural oak recruitment and restocking and mitigation programs may be severely limited unless herbaceous plant control and protection against small mammals and insects are part of management activities.*

During the past decade, scientists, resource managers, and conservation groups in California have become concerned about the lack of young trees in stands of native oaks (*Quercus* spp.) growing in the state's Mediterranean-like climate. Recruitment varies geographically and within species (Bolsinger 1988, Muick and Bartolome 1987, Swiecki and others 1993). Recruitment is relatively sparse in blue oak (*Q. douglasii* H. & A.) stands, which occupy about 1.2 million ha or 40 percent of all oak woodlands, and is almost nonexistent in valley oak (*Q. lobata* Née) stands (Bolsinger 1988). Unsuccessful blue oak and valley oak recruitment results from mortality at the seedling and sapling stages, rather than from inadequate germination and seedling emergence (Griffin 1971). The failure of most oak seedlings (plants less than 30 cm high) to reach sapling size (30–150 cm tall) or larger brings into question the sustainability of California's oak resources and their ability to support a variety of natural resource needs.

In the study presented, we examined the influence of weeds and small mammal and insect herbivory on emergence, survival, and growth of blue and valley oak seedlings developing from directly planted acorns.

Study Sites

All plantings were established between latitudes 35°15´ and 39°15´ N in California (*fig. 1*). Blue oaks were planted at the Canyon Ranch (CYNRN), San Luis Obispo County; the University of California (UC) Hopland Research and Extension Center (HREC), Mendocino County; and the UC Sierra Foothill Research and Extension Center (SFREC), Yuba County. Sites for valley oaks included Briones Regional Park (BRP), Contra Costa County; and HREC.

Understories at all sites are dominated by annual grasses. Throughout the study areas, annuals continue to grow until all available soil water is exhausted. A discussion of the ecology and composition of California's annual grasslands and the demise of the pristine perennial grasslands is presented by Heady (1977).

Elevation, rainfall, and soil characteristics at the several sites (*table 1*) represent conditions typical of those occurring in natural stands of the oaks found in the Coast Ranges, interior coastal ranges of the San Joaquin Valley, and western foothills of the Sierra Nevada in the Sacramento Valley.

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Figure 1—Locations of study sites.

Methods

Acorns, representing local genotypes, were fall-collected from several trees at each site and placed in cold storage (4 °C) until planting. Storage between 1 and 4 °C is recommended by Korstian (1927) and Harrington (1972) to retard germination without a reduction in emergence potential.

Blue and valley oak acorns were planted directly in field plots during November and December in 1986 and 1987. Blue oaks were planted at HREC in 1986 and at CYNRN and SFREC in 1987. Valley oak was planted at HREC in 1986 and at BRP and HREC in 1987. All sites were in open oak woodland, away from canopy influence and on terrain as flat as possible to reduce effects of slope exposure and inclination. All sites also were fenced to prevent browsing of seedlings by large herbivores, an acknowledged problem (Longhurst and others 1979, Duncan and Clawson 1980).

At each site, two levels of weed control (weed-free and the naturally occurring vegetation) were treatments in a randomized complete block. Herbicides were applied annually to eliminate weeds. The two treatments were replicated four times each. In each 100-acorn replicate, acorns were planted in four parallel rows of 25 each, with rows 30 cm apart and acorns within rows also 30 cm apart. Planting depth was 5 cm, a depth suggested for use in controlled environments (Lobel and George 1983) and considered a minimum to discourage

Table 1—Characteristics of the study sites

Location[1]	Elevation	Average annual precipitation	Soils: Surface soil texture	Depth	Estimated AWC[2]	Soil series[3]	Soil family
	m	*cm*		*cm*	*cm cm^{-1}*		
Blue Oak							
CYNRN	545	28	Clay loam	155	0.14-0.17	Ayar	Fine, montmorillo nitic, thermic Typic Chromoxererts
HREC	273	94	Loam	183	0.14-0.17	Hellman	Fine, mixed, thermic Mollic Palexeralfs
SFREC	182	72	Gravelly loam	53	0.11-0.16	Argonaut	Fine, mixed, thermic Mollic haploxeralfs
Valley Oak							
BRP	124	48	Clay loam	193	0.16-0.18	Botella	Fine-loamy, mixed, thermic Pachic Argixerolls
HREC	273	94	Loam	152	0.14-0.17	Yorkville	Fine, mixed, thermic Typic Argixerolls

[1]CYNRN = Canyon Ranch, HREC = UC Hopland Research and Extension Center, SFREC = UC Sierra Foothill Research and Extension Center, BRP = Briones Regional Park

[2]AWC = Available Waterholding Capacity

[3]All are upland soils except Botella which is alluvial.

disturbance by mice (Griffin 1971). This depth has been found to be a good compromise between improved protection from predation and reduced emergence that occurs from planting at a greater depth (Tietje and others 1991). After emergence, screens were placed randomly over half of the seedlings in each replicated treatment to protect them from herbivory by small mammals and insects. Screened and unscreened seedlings became subplots, creating a split-plot design.

Data evaluated by analysis of variance (ANOVA) included emergence, survival measured in spring of each growing season, and height of plants each fall. To increase the power of the ANOVA, data for each species were pooled by years in a repeated measures analysis. When there was a significant time interaction, ANOVAs for each year were used to assess treatment effects. This was done to ensure a conservative interpretation of data. For height measurements, the longest stem was used if branching occurred. Unless otherwise noted, significant differences are reported at the 95 percent level of confidence.

When necessary for the ANOVA, the arcsine transformation of percentage emergence and survival was used to maintain homogeneity of variances. The results presented are treatment averages for the original measurements.

Cages (closed cylinders 15 cm in diameter and about 40 cm high) made out of aluminum window screen material were used for protection at all but one location, CYNRN. At this site, 14-strand rigid plastic seedling protectors 5 cm in diameter, 30 cm high, and with a larger mesh were substituted. This material was used, because the threat from insects, primarily grasshoppers (*Melanoplus devastator* Scudder), was minimal.

Results

Blue Oak

For blue oak, average seedling emergence over all planting dates and sites was nearly a third greater ($P \leq 0.05$) with weed control, and average survival in this treatment was three times greater ($P \leq 0.01$) in 1995 (*fig. 2*). For seedlings growing with weed control, survival was different ($P \leq 0.01$) between protected and unprotected seedlings, but the absolute difference did not change significantly during the study. In 1995, survival for protected seedlings was about a fifth greater (*fig. 2*). Measured over the course of the study, the contrast in survival between protected and unprotected seedlings growing without weed control changed significantly ($P \leq 0.01$). Through interaction with time, survival of unprotected seedlings declined more rapidly; it was less than one-fifth that of protected seedlings ($P \leq 0.01$) in 1995 (*fig. 2*).

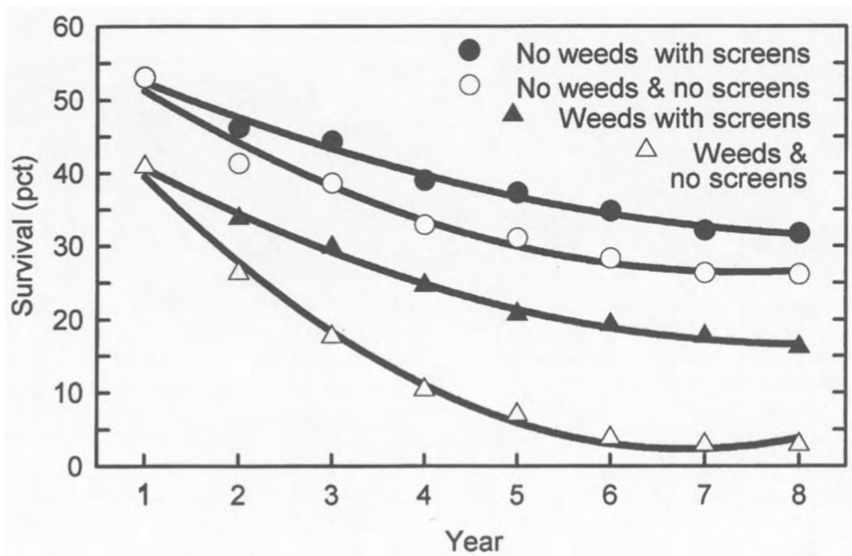

Figure 2—Average blue oak emergence and survival (percent of acorns planted) in three plantings. Values for Year 1 are percent emergence.

Where weeds were controlled, the height differential between protected and unprotected blue oak seedlings was nearly two-thirds ($P \leq 0.01$) in 1995 (*table 2*), but the difference in height was not an unqualified measure. As seedlings

Table 2—Average effects of weed control and screen protection on 1995 seedling height (centimeters) at three blue oak and at three valley oak sites

Species	Screen protection	Seedling height[1] Weeds present	Weeds absent
		cm	
Blue Oak	No	[2]	76b
	Yes	68b	124a
Valley Oak	No	[2]	68c
	Yes	80b	127a

[1]Values for each species not followed by the same letter are different ($P \leq 0.01$) by Least Significant Difference Separation.
[2]Inadequate survival for reliable estimates.

increased in size, screens were opened to prevent restriction of growth. This created access and permitted limited insect and small mammal herbivory, which affected measurements. Among seedlings with complete initial screen protection, the 1995 height of those growing with no weed control was only half that ($P \leq 0.01$) of those growing weed free (*table 2*).

Valley Oak

Average valley oak seedling emergence over all planting dates and sites was nearly two-thirds greater ($P \leq 0.01$) with weed control, and average survival in

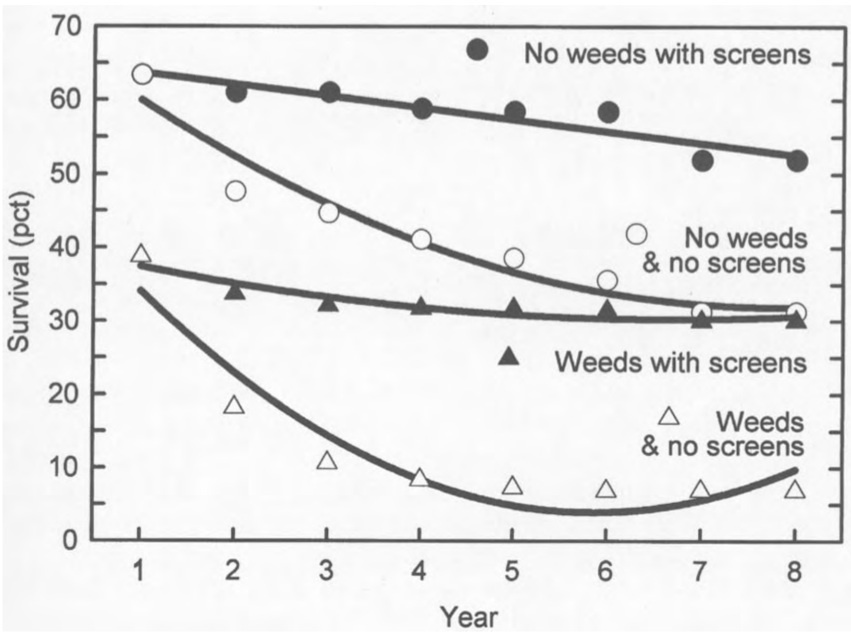

Figure 3—Average valley oak emergence and survival (percent of acorns planted) in three plantings. Values for Year 1 are percent emergence.

this treatment was more than double that without weed control ($P \leq 0.01$) in 1995 (*fig. 3*). In both main plot treatments, loss during the course of the study was more rapid for unprotected seedlings ($P \leq 0.01$). Through interaction with time, survival of unprotected seedlings growing with and without weed control was, respectively, 60 percent and less than 25 percent of that for protected seedlings ($P \leq 0.01$) in 1995 (*fig. 3*). Decline in survival of protected seedlings growing with weed control was due, in part, to pocket gopher (*Thomomys bottae* Eydoux & Gervais) herbivory that became serious after the second season.

In 1995, protected valley oak seedlings growing weed free were more than 85 percent taller than those unprotected in the same treatment ($P \leq 0.01$) (*table 2*). Between protected seedlings growing with and without weeds, the differential was about 60 percent ($P \leq 0.01$). Contrasted with blue oak, the average height of protected valley oak seedlings growing without weed control was nearly 20 percent greater ($P \leq 0.01$) than that of seedlings growing unprotected but weed free (*table 2*).

Discussion

The difference in mortality among blue oak seedlings growing with and without initial full screen protection was greatest in the absence of weed control; after seven seasons, more than five times as many protected seedlings were alive—16 percent vs. 3 percent (*fig. 2*). The difference was much smaller with weed control, about 1.2 times as many protected seedlings were present after seven seasons—32 percent vs. 26 percent (*fig. 2*). The best treatment—weed control with screens—contained more than 10 times as many seedlings as the worst treatment—no weed control and no screens. The differential effect of screens on survival was

Table 3—Statistical significance of contrasts (treatment effects and their interaction) identified by ANOVA of values for each of the 8 years shown in figs. 2 and 3

	Statistical significance (P) of contrasts[1]			
Contrasts	Year 1	Year 2	Year 3	Years 4-8
	Blue Oak			
Weeds	0.01	0.01	<0.01	<0.01
Screens	[1]n.a.	<0.01	<0.01	<0.01
Weeds × Screens	[1]n.a.	[1]n.s.	0.01	<0.01
	Valley Oak			
Weeds	<0.01	<0.01	<0.01	<0.01
Screens	[1]n.a.	<0.01	<0.01	<0.01
Weeds × Screens	[1]n.a.	[1]n.s.	<0.05	<0.01

[1]n.a. = not applicable; n.s. = not significant

due to an interaction with main plot treatments that developed with time (*table 3*).

Average survival of blue oak during the study period was influenced by geographic location. At CYNRN, it was 40 percent of the average value for HREC and SFREC, locations where average survival during the study was not different. This difference may be related to rainfall. At CYNRN, average rainfall is one-third that of the average for the other two locations. As in blue oak, the greatest difference in valley oak seedling survival was between protected and unprotected subplot treatments where weeds were not controlled; after seven seasons, four times as many protected as unprotected seedlings were alive—30 percent vs. 7 percent (*fig. 3*). With weed control, the difference was smaller; less than twice as many protected seedlings were alive after seven seasons—52 percent vs. 31 percent (*fig. 3*). After three growing seasons, there was no difference in survival between unprotected seedlings growing with weed control and protected seedlings growing without such control. As in blue oak, the best treatment after seven seasons was weed control combined with screen protection. There were more than seven times as many seedlings in this treatment compared with the worst treatment—no control with no protection. Over time, interaction developed between weed control and protection factors (*table 3*).

Of the three valley oak plantings, the most and least successful were consecutive annual plantings at HREC. During the planting seasons, rainfall at this site was 70-80 percent of average. Average annual rainfall at BRP is about half that at HREC, as it was during the planting season. Survival in the three plantings, affected by both physical parameters and pocket gopher herbivory, provided inconclusive evidence that location influenced plant performance.

The value of weed control was identified early in the study by Adams and others (1987), but it is not a unique observation. Throughout the East, Midwest, and Canada, the benefits of controlling weeds to promote survival and growth of oaks and other hardwoods propagated naturally and artificially are well documented (Bowersox and McCormick 1987, Siefert and Fischer 1985, von Althen 1987). In California, Griffin (1971) demonstrated that reduced precipitation, in addition to annual grass competition, greatly reduced blue and valley oak establishment.

As expected, the addition of screen protection in our study improved survival. Griffin (1976) observed that small mammals and insects continued to attack oak seedlings, even after exclusion of deer. In the eastern United States, rodents are the chief obstacle to reproducing oaks from seeded acorns (Johnson 1979, Krajicek 1955). Grasshoppers, a principal predator at several locations in our study, are favored by a cover of herbaceous plants that provides habitat for development and feeding (Linit and others 1986). They probably contributed more to damage among unprotected seedlings growing without weed control than to unprotected seedlings growing with weed control.

Shade produced by screens probably contributed to the differential in survival and height between protected and unprotected seedlings. Crow (1988) observed that seedlings of northern hardwoods, including those of northern red oak (*Q. rubra* L.), in the central United States generally benefit from shade because it reduces water stress by moderating temperatures and evapotranspiration. A more complete review of shade influence was presented by Adams and others (1992). In our study, we believe that screens provided an element of protection against excessive transpiration, but the shade factor and its unmeasured positive effect could not be separated from the value of screens as protection against herbivory.

Screens, interacting with the environment, also may have contributed to a lower rate of loss for protected valley oak compared with protected blue oak in both main plot treatments, weed control and no weed control. In contrast, comparisons of the loss rate between unprotected seedlings of the two species in each treatment showed no difference.

The concentration of planted acorns in this study may have contributed to rodent herbivory. Because the fossorial pocket gopher locates its food primarily by odor (Hungerford 1976), predation by this rodent may have been encouraged by closely spaced seedlings in geometric patterns, a factor that may have influenced herbivory by other small mammals as well. Seedlings growing in patterns approximating the more random, natural distribution of oak trees may be less vulnerable to both aboveground and belowground attack.

Experience suggests that pocket gophers can present a prolonged threat. Roots of oaks are vulnerable to attack from these small mammals until trees are 5 cm or more in diameter at the base. The use and value of underground screens as protection against the rodents have been reported (Adams and Weitkamp 1992, Adams and McDougald 1995).

Supporting Studies

Weed-Control Strategies

An unpublished supporting study conducted by two of the authors evaluated alternative weed–control strategies as they might affect survival and growth of 2- to 3-month-old nursery stock protected from large herbivores and initially screened against small mammals and insects (Adams and Sands 1995). At HREC and SFREC, three successive blue oak plantings were established in winter 1987–88, 1988–89, and 1989–90 using the transplants for evaluation of three weed control strategies: (1) a one-time, post-planting application of herbicides, (2) porous plastic (PP) mulch mats, and (3) impervious plastic (IP) mats. These were compared with no weed control.

For promotion of survival, no one weed control strategy was superior. In 1995, average survival of blue oak seedlings with some type of weed protection was more than three times that with no control.

At both sites, more growth occurred with the two types of plastic mats, and seedlings growing with IP mats were tallest. The greater height of seedlings observed in the IP mat strategy may have been a product of more effective weed suppression over time and the influence of IP mats on the soil environment.

Survival in the IP mat treatment was less in the 1989-90 plantings than in the 1988-89 plantings when measured in spring 1992. Mortality was attributed to depredation by rodents, particularly meadow voles (*Microtus* spp.), which caused the majority of mortality and continue to girdle seedlings. The IP mat weed control strategy appeared to aggravate the problem by providing cover for rodents. By spring 1993, the difference measured in 1992 disappeared.

A contributing factor to rodent damage in this study was absence of all weed control (with the exception of applied weed-control treatments) within the half-acre enclosures used. The accumulation of biomass (primarily dead annual grass) apparently created habitat attractive to rodents. The accumulation of biomass also provided attractive habitat for grasshoppers, and the insects defoliated many seedlings, especially at SFREC in 1990.

Herbicides for control of weeds, as used in this study, were considered the most practical strategy. This conclusion was based on cost and the potential for synthetic mulch mats to aggravate rodent depredation.

Seeded Acorns and Nursery Stock Compared

In another unpublished study, survival and growth of blue and valley oak seedlings developing from seeded acorns and 2- to 3-month-old nursery stock were compared at several locations beginning in 1988–89 (Adams and others 1995). All seedlings were protected from large herbivores and grown weed free with half of each plant material initially screened against small mammals and insects.

After 6 years, average survival of screened blue oak seedlings developing from nursery stock was 80 percent, about a third greater than for those developing from seeded acorns. Survival of unscreened plant material was not different by class, but it was much less than either group of screened seedlings; the average was about 25 percent.

For valley oak, no difference in survival between classes of plant material could be measured. At one of the two planted sites, ground squirrels (*Spermophilus beecheyi* Richardson) attacked nursery stock immediately after planting and caused severe loss. At the second site, survival of all but one group of seedlings was high, nearly 100 percent. Only survival of unscreened seedlings developing from seeded acorns was different, about 90 percent.

Protection, but not class of plant material, enhanced growth of both species. After 6 years, the average height of protected blue oak seedlings was double that of unprotected seedlings, and in the valley oak plantings, protected seedlings were a third taller.

In this study, as in the others, rodents were a major cause of mortality. Selective attack on valley oak transplants by ground squirrels may have been encouraged by the cultural practices used during propagation. The seedlings were well watered and fertilized. Frequent watering during propagation may have leached tannins from the acorns. Tannins are believed to discourage consumption of the embryo-containing apical portion by eastern gray squirrels (*Sciurus carolinensis* Gmelin), several other vertebrates, and acorn weevil larvae (*Curculio* sp.) (Steele and others 1993). There is a rich literature describing the influence of fertilizer on herbivory. For example, fertilized young conifers are more likely to be attacked by rodents than unfertilized trees (Gessel and Orians 1967, Sullivan and Sullivan 1982). Enhanced palatability of nursery stock may explain the attack. Where ground squirrel populations are high, control may be necessary to prevent major seedling losses.

The temporal occurrence of other rodents, such as meadow voles, also was noted. For several years, voles damaged many seedlings at one valley oak site and at one blue oak site. Gophers were a chronic problem at all sites, but attack usually was localized and not general. As in the other studies, grasshoppers presented a problem, but their severity may have been reduced by grazing of the surrounding area, which reduced herbaceous growth and its value as cover for the insects.

While the results from this study strongly suggested that 2- to 3-month-old blue oak nursery stock is more likely to survive than seedlings developing from seeded acorns, initial protection from herbivory clearly was needed to take advantage of this potential.

Among sites in the study, there were great differences in annual rainfall. For the first two seasons, rainfall was 50 percent of average at the most xeric sites and 70-100 percent of average at the more mesic sites. Average rainfall during the first two seasons at the more mesic sites was nearly three times greater than at the dryer sites. However, survival of blue oak did not reflect these differences; in 1995, survival was greater at the most xeric site. It is tempting to hypothesize that climatic adaptation of blue oak represents a spectrum, but the spatial and temporal influence of small mammal and insect herbivory and other biotic factors make this speculation risky.

Conclusions

Weed competition can severely limit emergence of blue and valley oak seedlings developing from planted acorns and limit survival of both these and seedlings developing from 2- to 3-month-old nursery stock. More importantly, weed competition may prevent the development of seedlings into saplings. Competition may be the most important obstacle to oak recruitment; it appears necessary to maintain new plantings weed free through at least the first growing season. However, weed competition is only one problem.

Protection of oak seedlings and saplings against mammals and insects also is important. Protection can be as critical as weed control. Herbivory may vary with time and location, but some level of aboveground protection usually will be required until young oak trees are big enough to resist attack.

Large herbivores are a recognized problem, but small mammals also can present a threat. Among the second group are black-tailed jackrabbits (*Lepus californicus* Gray), omnivores such as raccoons, and a host of rodents. Common among the latter are rabbits (*Sylvilagus* spp.), meadow voles, deer mice (*Peromyscus maniculatus* Wagner), and pocket gophers, all known threats. Grasshoppers also can be a problem. Protection, as well as control of weeds, may be necessary to ensure success of restocking and mitigation programs and natural recruitment.

With protection from small mammals and insects, seedlings developing from 2- to 3-month-old nursery stock and growing weed free may have a survival advantage over those produced from directly seeded acorns growing under the same conditions. However, costs of propagating, transporting, and planting this plant material probably will make it economically unattractive for large-scale use where resource values per unit area are low, such as on rangelands, a conclusion reached by Standiford and Appleton (1993).

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