Artificial Regeneration of Blue and Coast Live Oaks in the Central Coast[1]

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Abstract: The primary goal of this study was to find economical and effective planting techniques that will ensure the establishment and early survival of coast live oak (*Quercus agrifolia* Née) and blue oak (*Q. douglasii* H. and A.) in the Central Coast region of California. Eight treatments were evaluated ranging from unprotected seed spots to those protected by 1/4-inch hardware cloth exclosures. Planting was repeated for two years. Seedling establishment varied significantly among study sites and between planting years. Poor germination and survival was attributed to below normal rainfall before and during the study. Seedling survival was enhanced with the use of animal exclosures and somewhat by shade. Blue oak establishment was somewhat better than that for coast live oak.

Lack of adequate regeneration of several woodland oak species is a major hardwood problem in California (Bartolome and others 1987; Bolsinger 1988; Griffen 1976; Johnson 1985). Many factors either individually or together impact acorns and the seedlings that develop from them. Acorns are a primary food for many animals including cattle, deer, turkeys, pigs, and assorted rodents. Birds and insects are extremely important factors in acorn utilization and seedling mortality (Griffin 1980; Brown 1980). Grazing by domestic livestock has been identified as the most persistent pressure on oak reproduction since the introduction of livestock by the Spanish in the late 18th century (Rossi 1980). However, excluding livestock from an area has not guaranteed seedling establishment (Griffin 1980). Where cattle and deer are excluded, small rodents, especially gophers, mice, and ground squirrels seem to be the major cause of seedling mortality (Griffen 1976; Borchert and others 1989; Adams and others 1987). The increase in small mammal populations is likely due to an abundance of annual grass seeds and roots and a reduction of predators.

Competition from annual grasses and herbaceous weeds for moisture, light, and nutrients also affects the survival of oak seedlings (Adams and others 1987; McCreary 1989). Moisture stress is believed to be an extremely important cause of seedling death, especially on marginal sites and during years of low rainfall. Blue oak (*Quercus douglasii* H. and A.) establishment has been found to be positively associated with increasing canopy cover and more mesic sites (Borchert and others 1989). On north-facing sites or partial shade, seedlings are able to survive in a grass cover even in dry years (Griffin 1980). Weed control in late winter or spring will decrease soil moisture loss due to transpiration. Weed control will also reduce the impact of pocket gophers and insects by removing their food source near the planting sites.

The overall objective of this study was to determine practical and economical methods of successfully establishing blue oak and coast live oak (*Q. agrifolia* Née) regeneration. Factors evaluated include three types of animal exclosures, light exposure (open versus canopy shade), and weed control to reduce moisture stress. The study was carried out on four planting sites in the Central Coast of California for two consecutive years to account for climatic variation.

STUDY AREAS

Blythe Ranch

The Blythe Ranch site is about 8 miles northwest of Paso Robles; descriptive characteristics are listed in table 1. The predominant vegetation is a woodland mixture of individual trees and small stands of coast live oak and blue oak with an occasional valley oak (*Q. lobata* Née) and it is interspersed with small areas of chaparral and open grassland. The soil under the two oak species is distinctly different even when the trees are in close proximity of each other with the coast live oak soil being decidedly more sandy than the blue oak soil.

A resident herd of about 20 cattle grazed the site continuously during the study. Wildlife typical of the coastal area is abundant including mule deer (*Odocoileus hemionus*), pocket gopher (*Thromomys bottae*), ground squirrels (*Spermophilus beecheyi*), and several flocks of wild turkeys (*Meleagris gallopavo*).

U.C. Hastings Reservation

The vegetation at Hastings Reservation is similar to that at Blythe Ranch with individual trees and small stands of coast live oak and blue oak, but with a greater component of valley oak. Wildlife species are abundant; there were no cattle or other livestock on this area.

[1]Presented at the Symposium on Oak Woodlands and Hardwood Rangeland Management, October 31-November 2, 1990, Davis, California.

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Table 1—*Name, location, and physical characteristics of the four oak regeneration planting sites*

Name	Location	Elevation (ft.)	Soil	Rainfall (in.)[1]	Species	Cattle	Aspect and Slope
Blythe Ranch	8 miles NW of Paso Robles	725	Sandy loam (CLO) to Clay loam (BO)	24 (10-34)	Coast live oak Blue oak	Yes	SE 10-40%
U.C. Hastings Reservation	26 miles SE of Carmel	2,200	Sandy loam with clay hardpan	20 (12-40)	Coast live oak	No	SE 10-40%
Agua Escondido (USFS)	20 miles SE of San Luis Obispo	2,490	Clay loam	— (11-16)	Blue oak	Yes	SE 15-20%
Benedict Ranch	10 miles W of Buellton	820	Santa Lucia series mixed with small rocks	14 (9-16)	Coastal live oak	Yes	N 10-15%

[1] Rainfall data collected locally at the Blythe Ranch and U.C. Hastings Reservation; data for other sites taken from nearest official weather station. First number is long-time average; numbers in parenthesis are for 1985-1989.

Agua Escondido

Agua Escondido is the most xeric of the test sites. Blue oak is the dominant tree species forming a small wooded savanna in a sea of chamise chaparral. Various Mediterranean herbaceous plants form a continuous ground cover. The area was grazed in 1987-88 by a herd of Brahman cattle.

Benedict Ranch

Coast live oak is the predominant tree species intermixed with small areas of grass and coastal sage. Over forty head of cattle grazed the area for a few months during the 1988 growing season, and a few horses had been pastured in the area during most of the study.

METHODS

Treatments

The eight planting treatments compared in this study (table 2) fall into the following three general categories: unprotected seed spots (Treatments 1-3), weed control-mulch (Treatment 4), and three types of animal exclosures (Treatments 5-8). All of the treatments were established in full sunlight at all sites or in the shade as noted in table 2.

Treatment 1 is a basic "control" planting without site preparation or weed control, and it simulates natural seedling establishment. Treatments 2 and 3 are the controls for the different levels of site preparation used in Treatments 5 to 8. Weed control was obtained either by scalping (scraping away herbaceous vegetation) or with black, 2-foot-square woven plastic sheets pinned in place with U-clips.

Three levels of predator exclusion were evaluated. In Treatment 5, only cattle were excluded from 40-foot-square barbed wire exclosures. Treatment 6 involved the use of 3-foot-high by 2-foot-diameter hog wire exclosures that were designed to keep out all large mammals. Treatments 7 and 8 involved the use of 1/4-inch hardware cloth exclosures that were 4 inches in

Table 2—*Study design and number of seed spots per treatment by test site and exposure for a single species*

	Test Area[2]				Total
	---------- I ---------		---II,III, IV-----		Seed
Treatment[1]	Open	Shade	Open	Shade	Spots[3]
1. Unprotected control, not predug or scalped	25	25	25	25	200
2. Unprotected, not scalped	25	25	25	25	200
3. Unprotected	100	100	25	25	350
4. Weed mats, unprotected	25	25	25	—	125
5. Cattle excluded	100	100	—	—	200
6. Large mammals excluded	25	25	25	—	125
7. Small and large mammals excluded	25	25	25	—	125
8. Small and large mammals excluded, mechanical clipping	25	25	25	—	125
Total seed spots:	350	350	175	75	1450

[1] Unless otherwise noted, all treatments include predigging and scalping.
[2] Test Area I = Blythe Ranch; Area II = Hastings Natural History Reservation; Area III = Benedict Ranch (coast live oak); Area IV = USFS site at Agua Escondido (blue oak).
[3] There were 1,450 see spots/species/year for a grand total of 5,800 for the study.

diameter and extended 12 inches above and 12 inches below the ground level. All animals are excluded except small insects. Mechanical clipping, Treatment 8, is a technique that is used to simulate animal browsing when there is no way to control the wildlife population. The above ground part of a seedling was cut back to ground level in late spring.

Planting Technique

The location of each seed spot was preselected and marked with a 2-foot-long 1/4-inch iron rebar stake. Except for Treatment 1, each seed spot was predug with a 4-inch power auger to a depth of 18 inches. Where required, a hardware cloth exclosure was installed and the soil refilled. Three acorns were planted at each seed spot between December, 1987, and January 1989. For the first year's planting, the acorns were placed straight down, point first, with the basal one-third of the acorn exposed. The second year, the acorns were pregerminated (Schettler and Smith 1980) and planted sideways 1 to 2 inches below ground.

Seed Collection and Storage

Acorns were collected directly from trees in October and November as close to each planting site as possible. An ample supply of blue oak acorns was available on each test site each year of planting. However, almost no coast live oak acorns were available at the Blythe and Hastings sites in 1987 and 1988.

The acorns collected in 1987 and 1988 were air-dried for several days and were then stored in plastic bags at about 38°F. Excess acorns were refrigerated until May, 1990, when a germination test was run to determine if the acorns were still viable.

Design and Analysis

An overall picture of the study design can be obtained from table 2 which lists the number of seed spots per treatment for each test site. Five 40-foot-square cattle exclosures were built on the north side of an individual tree with two-thirds of the exclosure in the open and one-third under the canopy. All the treatments for both planting dates were then randomly assigned to pre-selected seed spots. Logistic linear regression analysis was used to evaluate test results. Planting success was rated on the basis of at least one live seedling per seed spot. Sampling was done during late spring, after the first year's planting and again in late summer, 1988, and again in 1989. Germination for the second year's planting was evaluated in late summer, 1989.

Treatment Cost

An estimate of the cost for construction and setup of the animal exclosures and time required to predig a seed spot are listed in table 3. A fairly wide range in labor requirements is provided. Time for a specific job varied considerably depending on site conditions (e.g., loose versus hard soil), equipment availability, worker experience, etc. These figures should give a "ball-park" estimate of labor requirements and material cost.

Table 3—*Approximate labor requirements and material costs needed to fabricate and install the various items listed. The times and cost do not include site selection, supervision, travel time, etc.*

Item	Labor Requirements	Material Costs per unit[1]
Cattle exclosure 5-strand barbed wire 40 foot-square	[2]10-13 hours	$148.68
Large mammal exclosure hog wire	8-15 minutes	$2.07
Small mammal exclosure 1/4" hardware cloth	8-17 minutes	$0.87
Weed mats	1.5-2.5 minutes	$0.48
Pre-digging seed spots.	0.5-2.0 minutes	none

[1] Does not include the cost of equipment to manufacture or set up an item.
[2] Involved two workers plus an operator and tractor fitted with a 9-inch auger.

RESULTS AND DISCUSSION

Test Location

There was a considerable amount of variation in seedling survival among the four planting locations (figures 1-5) with the year of planting a confounding factor. Seedling establishment ranged up to 100 percent at Blythe in 1987-88 to less than 20 percent for both years of planting at the Benedict location.

Blythe Ranch

By far, the best initial seedling establishment obtained with the first year's planting was at Blythe. Percent seedling survival in May, about 5 months after planting, ranged from 52 to 96 percent for blue oak and from 48 to 100 percent for coast live oak (figure 1). Seedling survival dropped dramatically by the end of the first summer, especially for the coast live oak seed spots in the open where survival ranged from 0 to about 32 percent, except for the small mammal exclosures where over 80 percent of the seedlings were still alive. Overall, blue oak had less decline in survival over the summer than coast live oak, and the best establishment was obtained with the small mammal exclosures.

One explanation for the higher seedling survival at Blythe, compared to the other study locations, is that it was planted

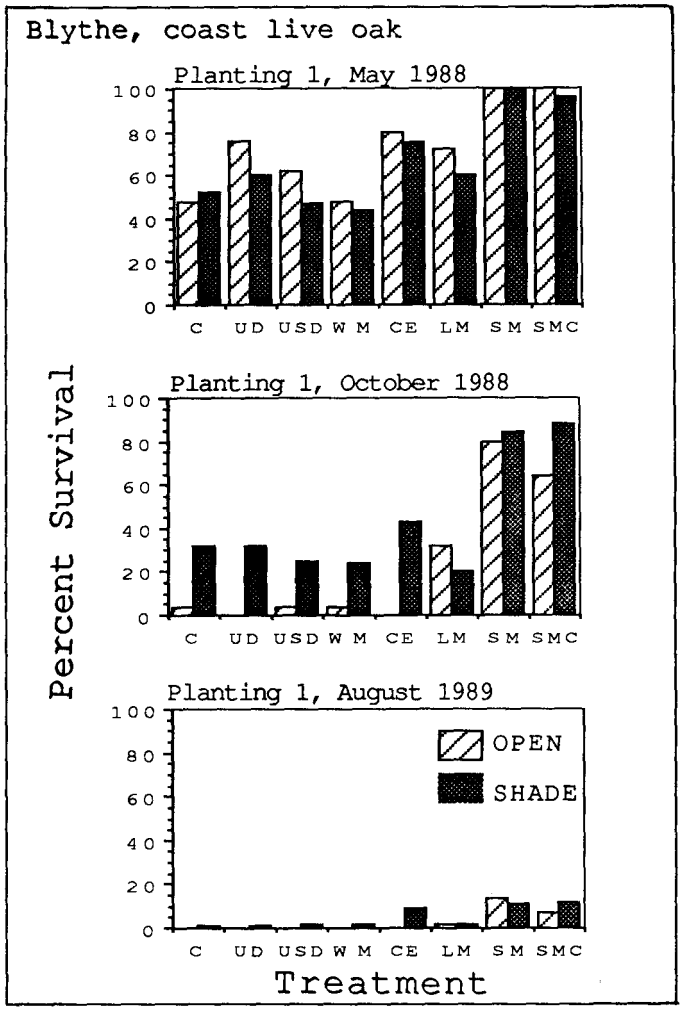

Figure 1—Percent survival of coast live oak seedlings over a 2-year period at the Blythe test site near Paso Robles. Planting 1 was done in December 1987. Treatments are as follows:

C .....Control, not scalped or predug
UD.....Unprotected, not scalped
USD .....Unprotected
WM .....Weedmats
CE .....Cattle excluded
LM .....Large mammals excluded
SM .....Small mammals excluded
SMC .....SM and clipped

Note: unless other wise stated, all treatments were predug and scalped.

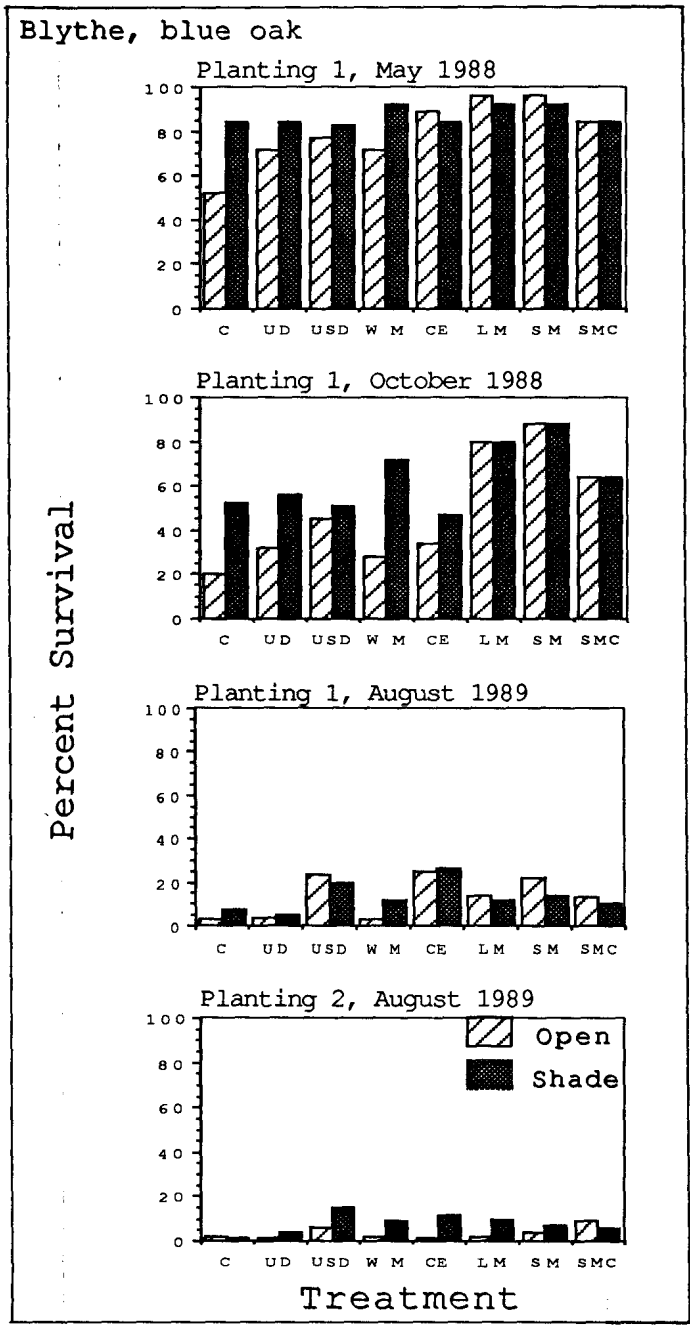

Figure 2—Percent survival of blue oak seedlings over a 1- or 2-year period at the Blythe test site near Paso Robles. Planting 1 was done in December 1987 and Planting 2 in January 1989. See Figure 1 for treatment description.

almost a month earlier. Early germination and root development would better prepare these seedlings for the dry months that followed than the acorns that were planted a month later and had less time to become established.

Results of the second year's planting at Blythe were very disappointing. Almost no coast live oak became established and blue oak establishment was not much better (figures 1 and 2). As in the previous 2 years, less than normal rain fell after December. Acorn predation began within a couple of weeks after planting. Several of the unprotected coast live oak seed spots were partially excavated to a depth of 1 to 2 inches. However, no predation of blue oak seed spots was observed at any time. The fact that almost no coast live oak acorns had developed at the study site during the first 3 years of this test may account for its selective predation. Within 4 weeks after planting, all of the remaining unprotected coast live oak acorns were removed by a flock of resident wild turkeys. The few seedlings that were established that year were mostly those protected by small mammal exclosures.

U.C. Hastings Reservation

Initial establishment of coast live oak seedlings at Hastings was fairly high for the protected seed spots with almost 55-65

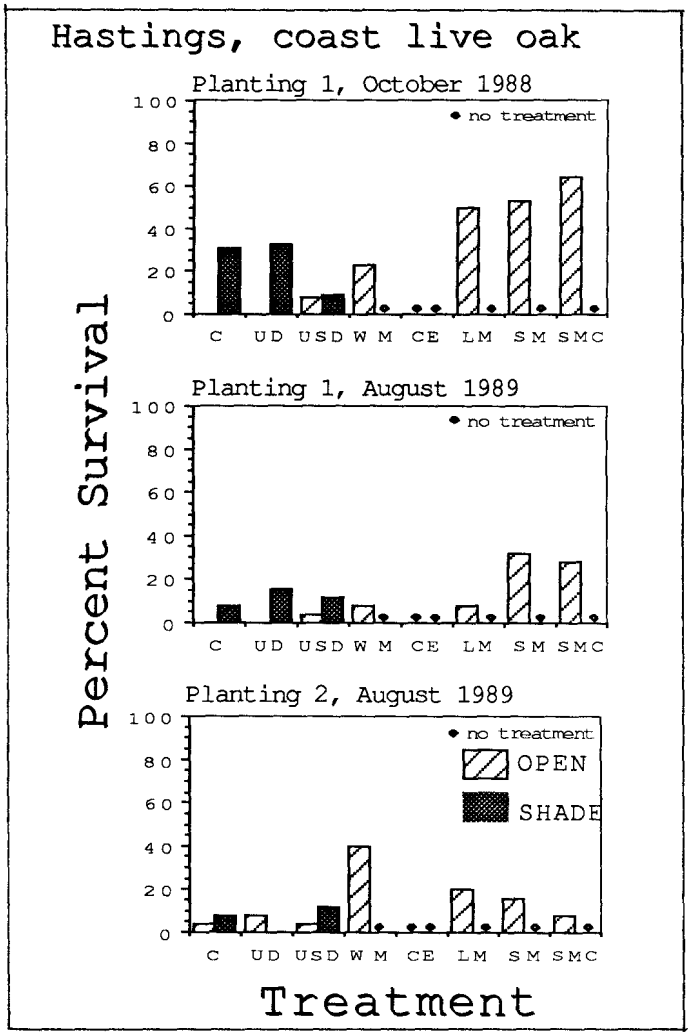

Figure 3—Percent survival of coast live oak seedlings over a 1- or 2-year period at the Hastings test site. Planting 1 was done in December 1987 and Planting 2 in January 1989. See Figure 1 for treatment description.

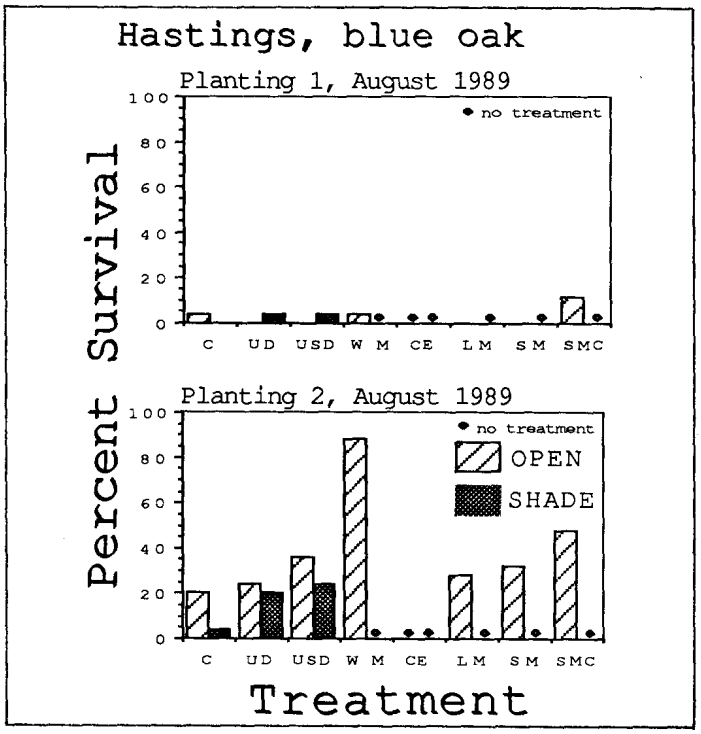

Figure 4—Percent survival of blue oak seedlings over a 1- or 2-year period at the Hastings test site. Planting 1 was done in December 1987 and Planting 2 in January 1989. See Figure 1 for treatment description.

percent of the plants still alive after the first summer (figure 3). By the end of the second summer, 30 percent of the seedlings protected by the small mammal exclosures were still alive, a slightly higher percentage of seedling survival than at Blythe, but not significantly higher. On the contrary, coast live oak germination for the second year's planting was low, apparently the victim of the continuing drought. The best survival was obtained with weed mats; they had little or no positive effect on the first year's planting survival.

Blue oak seedling establishment with the first year's planting was extremely low with only a few percent of the acorns germinating (figure 4). It was not apparent why it was less successful than coast live oak in getting established the first year. Blue oak survival was considerably better with the second planting, especially with weed mats which resulted in over 85 percent survival (figure 4).

Agua Escondido

Seedling establishment at Agua Escondido was low the first year except for seedlings protected by small mammal exclosures (up to 50 percent survival at the end of the first summer, figure 5). However, seedling survival with the second year's planting was much higher for all treatments, ranging from 35 to 65 percent. There were no obvious reasons for the higher germination and survival the second year. Planting the first year was in December followed by 8.6 inches of rain between January and June. Planting the second year was in January with only 3.9 inches of rain until June. Based on just the amount of rainfall after planting, seedling establishment should have been extremely low instead of better.

Benedict Ranch

Coast live oak establishment for both years at the Benedict site was extremely low, less than 10 percent for both years of planting. Many of the acorns did not even germinate. The rocky soil, with its large air spaces, was not a favorable environment for satisfactory germination and development, especially when rainfall was below normal.

Species

Blue oak survival was significantly higher than coast live oak's for both years of planting and at all sampling dates with the exception at Hastings when only a few blue oak became established from the first year of planting, regardless of treatment (figure 4).

Because blue oak grows on more xeric sites and it better adapted to drought conditions than coast live oak (Matsuda and

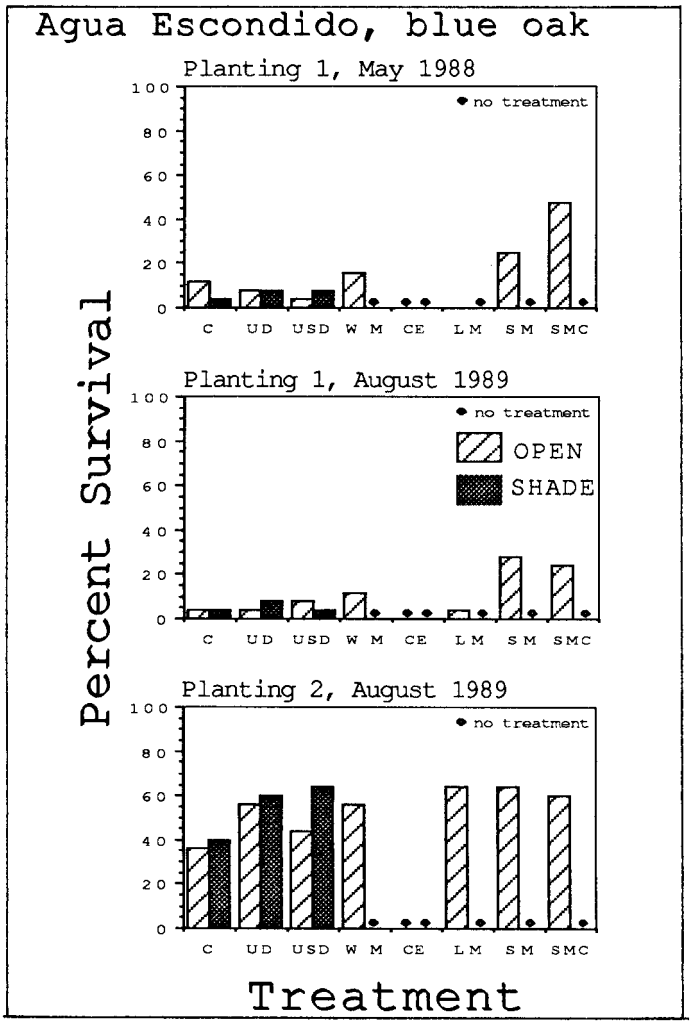

Figure 5—Percent survival of blue oak seedlings over a 1- or 2-year period at the Agua Escondido test site. Planting 1 was done in December 1987 and Planting 2 in January 1989. See Figure 1 for treatment description.

McBride 1986), it might be expected to have a higher survival rate than coast live oak during low rainfall years. The data from this study appear to substantiate this. However, even though blue oak performed better than coast live oak in this study, both numerically and statistically, its percent survival one year after planting was not high enough for the planting operation to be considered successful.

Light Exposure

In general, shade improved the odds for survival at the end of the summer for both years of planting. These results confirm other reports that oak regeneration is usually greater under tree canopy than it is in the open (Griffin 1971, Griggs 1987). More specifically, Bartolome and others (1987) indicate that it was more common to find oak saplings at the canopy edges than under the canopy or in the open. However, by the end of the second summer after planting (figures 1-2), seedling survival had dropped to such a low value that canopy effect was no longer of practical importance.

Treatments

Unprotected Controls (Treatments 1-3)

There was no significant difference in seedling establishment and survival among the three treatments involving unprotected seed spots. Compared to Treatment 1, which had no site preparation and amounted to simply planting acorns directly into the ground, there was no apparent advantage gained by predigging the seed spots or scalping the soil around a seed spot. Consequently, these cultural activities should not have had any effect on the other treatments.

Weed Mats (Treatment 4)

The weed mats effectively kept weeds away from the seed spots, but there appeared to be little positive effect on seedling survival for the first year of planting. In fact, they actually seemed to have a negative effect. This was unexpected because of the drought conditions during the study. Any treatment that reduced moisture stress should have been somewhat beneficial. The black mats may have caused elevated soil temperatures that were detrimental to the seedlings. At any rate, the weed mats had a strong positive effect on seedling survival at Hastings with the second year of blue oak planting (figure 4) and to a lesser extent with coast live oak (figure 3). There was no obvious reason for such a positive effect the second year and only at one location.

Animal Exclosures (Treatments 5-8)

Cattle alone had no significant impact on seedling survival, but where both cattle and deer were excluded (Treatment 5, large mammal exclosures), survival was significantly increased. Although this suggests that deer alone or in combination with cattle were responsible for seedling losses, there was no obvious field evidence for this conclusion.

The small mammal exclosures significantly improved the odds of seedling survival, at least until the first fall season after planting. However, percent seedling survival a year later had dropped from about 80 percent to only about 10 percent at Blythe (figures 1 and 2). This decline in survival was most likely due to the effect of moisture stress and points out the need to wait at least two years after planting to realistically evaluate seedling survival.

Live seedlings in the small mammal exclosures (Treatment 8) were clipped off at ground level by hand in the spring of 1988 to simulate animal browsing. Clipping appeared to have little effect on seedling survival and was not carried out with the second planting.

The 1/4-inch hardware cloth exclosures may be too durable for practical field use. If left in the ground, there is concern that they will severely restrict root growth as a seedling gets older. Removing an enclosure after a seedling is well established is not practical because almost the whole enclosure has to be dug up to get it out of the ground. This would be time consuming and a bit traumatic for the seedling. Also, at a cost of at least $1.00 per

seed spot, including materials, construction, and installation, the hardware cloth exclosures would be too expensive for large field plantings.

Acorn Storage

There has been considerable debate about how long acorns can be stored and remain viable. White oak acorns are reported to be less durable than black oak acorns (Bonner 1979). Plumb and McDonald (1981) reported that scrub oak acorns, if air dried prior to cold storage, would remain viable for at least 15 months.

Results of a germination test, involving acorns collected for this regeneration study and acorns of other species stored during the same period, indicate that both white and black oak acorns will remain viable for at least 30 months. Percent germination for coast live oak and blue oak stored since October, 1987, were 30 and 46 percent, respectively. Coast live oak stored since October, 1988 and 1989, germinated at a rate of 40 and 100 percent, respectively. California black oak (*Q. kelloggii* Newb.) and canyon live oak (*Q. chrysolepis* Lieb.) were also viable after 2 years of storage (41 and 35 percent, respectively).

CONCLUSIONS

The results of this oak regeneration study varied from location to location and year to year at the same location, making it difficult to draw clearcut conclusions about the regeneration methods tested. There is little doubt that below normal rainfall during the 4 years of this study had an extremely negative effect on both acorn germination and subsequent seedling survival.

Even though some of the treatments resulted in statistically higher survival than obtained with the controls, the numerical results in terms of seedling survival were too low to have practical significance.

In summary, blue oak had a higher rate of survival than coast live oak. Planting in shaded sites increased the odds of seedling survival over planting in the open. Weed mats gave erratic results, but significantly increased seedling survival at a couple of sites in 1988. They need further testing. There was a clearcut advantage in using small, wire mesh cages to protect acorns and seedlings from animal depredation. Finally, cattle were not found to have any singular detrimental impact on oak survival.

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