An Evaluation of Coast Live Oak Regeneration Techniques[1]

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Abstract: *A test to evaluate four planting techniques for coast live oak (*Quercus agrifolia *Née) was established in spring 1992 on the California Polytechnic State University, San Luis Obispo, California. Treatments included tree shelters (Tubex®), oak leaf mulch, tree shelters plus mulch, and an unprotected control. Seedling survival 1 year after planting ranged from 14.3 to 37.1 percent. The greatest survival was obtained with oak mulch, and the tallest seedlings, but lowest survival, with tree shelters. Although the shelters enhanced seedling growth, the seedlings averaged only 5.9 inches in height at 1 year. Because of poor survival, empty planting spots were replanted in 1993, 1994, and 1995. By December 1995, average coast live oak stocking ranged from 60 to 74 percent, and height from 3.5 to 15.6 inches for the control and tree shelter treatments, respectively.*

This report describes a project in which several techniques were used to enhance the survival of direct seeded coast live oak (*Quercus agrifolia* Née). What was initially intended to be a 1-year planting project evolved into a 4-year planting "marathon." This is the only effort in California that we are aware of in which the same plantings spots were seeded 4 successive years to achieve as close to 100 percent stocking as possible. Surveys during the past several years indicate a general lack of adequate coast live oak regeneration throughout its range. Bolsinger (1988) reported that about 90 percent of the coast live oak type had few or no saplings or seedlings. And, attempts to artificially regenerate coast live oak in local wild environments have not been successful (Muick 1991, Plumb and Hannah 1991).

A myriad of causes have been identified to explain the poor success of both natural and artificial restocking (Davis and others 1991, Swiecki and others 1990). Swiecki and Bernhardt (1991) provide an excellent overview of the factors affecting the restoration of valley oak (*Q. lobata* Née). Most of these factors apply to coast live oak as well. Herbivory and moisture stress are two key factors negatively affecting both seedling establishment and survival. Mice (Davis and others 1991), deer (Griffin 1971), cattle (McClaran 1987), and grasshoppers (McCreary and Tecklin 1994) are some of the biota that can cause significant seedling losses. However, once established, oak seedlings can often survive stem and foliage losses because of their resprouting capacity. On the other hand, gophers can kill both seedlings and saplings, and they can destroy a root system, preventing resprouting (Adams and others 1992, Davis and others 1991, Lathrop and Yeung 1991). Where gophers are present, the root systems must be protected.

A wide variety of protective devices have been used to prevent herbivory, including window screens (Adams and others 1992, McCreary and Tecklin 1994), fencing (Davis and others 1991, Tietje and others 1991), and individual plant exclosures (Plumb and Hannah 1991, Swiecki and Bernhardt 1991). Plastic translucent tubes called tree shelters (Tubex®) have received considerable attention during the past few years (Costello and others 1991, Potter 1988). They are touted not only because they protect seedlings from herbivory, but also because they promote height growth (McCreary 1993).

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Moisture stress is a major environmental factor responsible for poor germination (Plumb and Hannah 1991) and seedling death (Barnhart and others 1991, Lathrop and Yeung 1991). Low rainfall, an obvious contributor to moisture stress, was considered the major reason for poor success of regeneration work during the latter part of the 1980's (Plumb and Hannah 1991). Other major causes of water stress are plant competition, particularly from annual grasses (Adams and others 1992, Davis and others 1991), and coarse soil textures (Plumb and Hannah 1991). Competing vegetation can be controlled with herbicides and mulching (Adams and others 1992, McCreary 1991). Irrigating young plants during the dry season has also been used in several oak regeneration studies (Costello and others 1991, Swiecki and Bernhardt 1991). The latter obtained better height growth with irrigation.

Some of the many factors that affect oak seedling germination and survival have been briefly noted. The main objective of the work reported here was to determine the effect of tree shelters, oak leaf mulch, and summer irrigation on coast live oak seedling survival. Because of low seedling survival, we decided to replant the same planting spots to determine how much additional work would be needed to achieve a high level of stocking.

Methods

Site Description

The study area is located on Radio Tower Hill (RTH), just west of the main California Polytechnic State University (Cal Poly) campus, San Luis Obispo, California. It is on a northeast aspect at about 400 feet in elevation with slopes between 10 to 40 percent. The test plots occupy about 0.5 acres in a long narrow strip between a ridge line and a stand of coast live oak along the northeast border. A preliminary analysis indicated that the soil is a loamy, mixed, thermic, ultric soil that was keyed out to be a Catelli coarse, sandy clay loam. Except for thicker "O" and "A" horizons, there is little difference between the soil in the grassy plot area and that under the adjacent oak canopy (*table 1*).

***Table 1**—Comparison of soil characteristics between the open grassy test area and under the canopy of the adjacent oak stand*

Site	pH	Soil horizon depth					Accumulated
		O[1]	A	B	BC	C	depth to "A" to "C"
		inches					
Open grass	5.4-5.7	0.4	1.6	8.3	5.1	13.8+	15.0
Oak canopy	5.5-5.8	0.8	4.7	8.7	3.9	9.9+	16.3

[1]Soil horizons are defined as follows: O = organic zone, A = mineral zone, B = accumulation zone, and C = unconsolidated parent material.

Annual grasses are the predominant vegetation on the project area with scattered northern monkey flower (*Mimulus aurantiacus* Curtis), coyote bush (*Baccharis pilularis* DC.), and California sage brush (*Artemisia californica* Less). There is also scattered advanced coast live oak regeneration in the annual grass along the upper edge of the oak stand, including several new seedlings along the canopy drip line. The oak stand is composed of a wide range of sizes and conditions of coast live oak. Photographic evidence over the past 82 years indicates that there has been a considerable increase in the size of the stand since 1908.

Although no formal animal monitoring was done, deer (*Odocoileus hemionus columbianus*) are often seen in the plot area. There was evidence of extensive pocket gopher (*Thomomys bottae* Eydoux & Gervais) activity at the beginning of the study that seemed to greatly increase in 1995. In some areas, exit and feeding holes are only 6 to 12 inches apart. Grasshoppers (species not identified) were present throughout the summer months; but in summer 1994, as noted by McCeary and Tecklin (1994) at the Sierra Field Station, there was a population explosion. It was common to find four or five grasshoppers on a single seedling. Leaf and stem damage was similar to that described by McCreary and Tecklin (1994)—leaves partially to completely gone and bark stripped from the smaller stems.

Treatments

This project included a small statistically designed regeneration test to compare the effectiveness of tree shelters and oak leaf mulch on coast live oak seedling survival and growth. Because of poor initial seedling survival, planting spots without a live seedling were replanted for 3 additional years. A small irrigation study was also established the third year of the project.

1991-1992 Activities

The Regeneration Test involved four treatments: (1) untreated control, (2) oak litter mulch, (3) tree shelters (4 feet tall and 3.5 inches wide), and (4) tree shelters plus oak litter mulch. The test consisted of 35 randomly located clusters, each containing four planting spots randomly assigned to the treatments. The planting spots in each cluster were in a square pattern and about 4 feet apart. Planting data, site preparation, seed source, and irrigation schedule are listed in *table 2*. All planting spots were pre-dug with a 6-inch power auger to a depth of 12 to 18 inches. An 18-inch long by 6-inch diameter cylinder of 1-inch mesh chicken wire was placed in each hole for gopher protection; the holes were then refilled with

Table 2—Planting date, seed source, monthly irrigation schedule, and other treatment factors for the four planting cycles of the Coast Live Oak Regeneration Test

	Year of planting			
Cultural factors	1991-1992	1992-1993	1993-1994	1994-1995
Planting date	Late April	Late January	Late February	Early February
Site preparation	Pre-dug holes to 18 in., scalping	Litter replacement, scalping	Litter replacement, scalping	Litter replacement, no scalping
Seed source	Poly Canyon	Poly Canyon	Mixed[1]	Mixed
Acorns per planting spot	2	3	2	2
Irrigation schedule	June-Sept.	April-Oct.	June-Sept.	June-Sept.
Water per planting spot	1 gal.	0.5 gal.	0.5 gal.	1 gal.
Method of irrigation	1-gallon[2] container	Hand irrigation	Hand irrigation	4-gallon[3] container

[1]Acorns from Cal Poly Campus and from Pleasanton Ridge, Pleasanton, CA.
[2]Water for each planting spot was supplied from a 1-gallon plastic container with a small hole punched in the bottom.
[3]Water for all four treatments was supplied from a 4-gallon container fitted with four 1-gallon/hour drip emitters.

the excavated soil. A 5-ft square area containing each cluster was scalped to mineral soil in March 1992 to control grass competition.

Acorns were picked in October from a tree in Poly Canyon, about 1 mile across the campus from RTH. They were air-dried for about 10 days, then stored in plastic bags in a cold box at 38 °F. About 2 weeks before planting, the acorns were placed in plastic bags containing moist vermiculite and stored at 70-75 °F. Two pregerminated acorns with radicles approximately 1/4 inch long were sown in each planting spot during the first week of April. The control planting spots received no additional preparation. Oak leaf litter for the mulch treatment was collected from the adjacent oak stand and spread over a planting spot to a depth of about 2 inches. The litter was held in place with a 1.5- by 1.5-ft piece of chicken wire secured in place with hemp staples. Tree shelters were secured with 3/4-inch thick wooden stakes; the tops of the shelters were covered with fine plastic mesh or wire to keep out birds and other small animals.

Irrigation for the Regeneration Test was applied to each planting spot at the rate of 0.5 or 1.0 gallons per month from late spring to early fall (*table* 2). Seedling survival (*fig. 1*) and height (*fig. 2*) were measured several times from May 1992

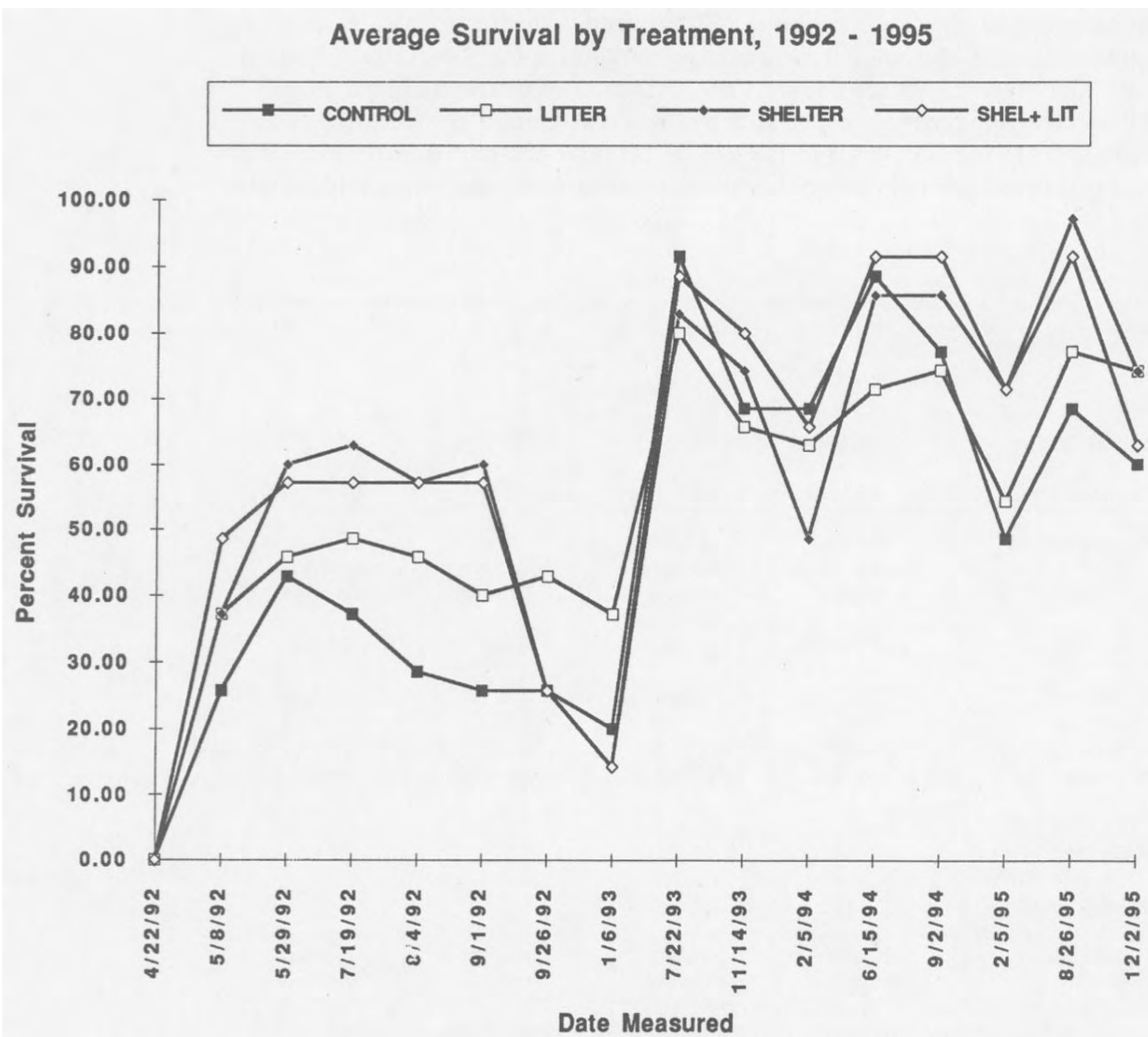

Figure 1—Percent survival of coast live oak seedlings for four planting cycles beginning in 1991. A dramatic decline in survival occurred each fall; little increase in stocking was gained after the second planting.

until January 6, 1993. All sample dates for 1992 and subsequent planting years are shown in *figures 1* and *2*.

1992-1993 Activities

Planting spots without a live seedling were replanted in late January with three germinating acorns (*table 1*). Each cluster was rescalped and the oak litter mulch replaced. Monthly irrigation of 0.5 gallons per planting spot began in late April and continued until October.

1993-1994 Regeneration Activities

All planting spots without live seedlings were replanted with two germinating acorns in late February (*table 3*). We made no effort to keep track of the acorn source for this or the following year's planting. Acorns were either from Poly Canyon or Pleasanton, California. The litter treatments were again refurbished and each 5- by 5-foot plot area rescalped.

A small irrigation study was established in March 1994 to compare two rates of irrigation (1/2 and 1 gallon per planting spot) and a nonirrigated control. Ten treatment clusters were arbitrarily dispersed throughout the Regeneration Test area with each treatment randomly assigned within a cluster. Each planting spot

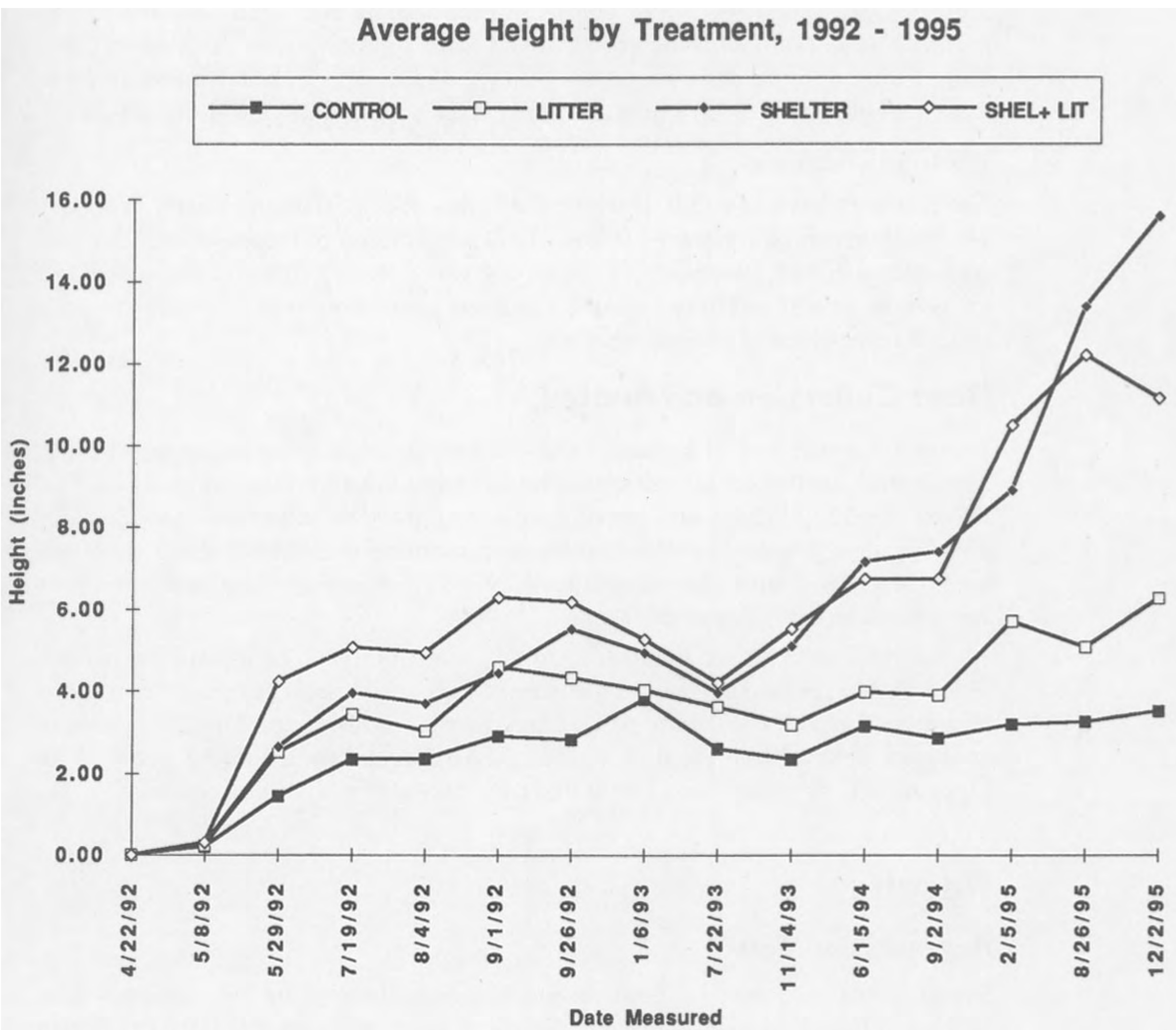

Figure 2—Average height of the coast live oak seedlings protected by tree shelters dramatically increased in 1995. However, death of several of the tallest seedlings (up to 43.3 inches tall) between August and December 1995 resulted in a drop in average seedling height for the tree-shelter-plus-litter treatment.

Table 3—Planting date, monthly irrigation schedule, and other treatment factors for the Coast Live Oak Irrigation Study

	Year of research activity	
Cultural factors	1993-1994	1994-1995
Planting date	Late February	Early February
Acorns or seedlings per planting spot	2	2
Irrigation schedule		
Water application per planting spot	June-Sept. Variable[1]	June-Sept. Variable[2]

[1]Three rates: 0, 0.5, and 1 gal. per planting spot.
[2]Nonirrigated control plots received 0.5 gal. water per planting spot on the June irrigation date.

was pre-dug with a 6-inch diameter auger, lined with chicken wire and refilled. Six-inch diameter chicken wire cylinders 12 inches tall were attached to the top of the gopher exclosures to reduce aboveground herbivory. Three germinating acorns were sown at each planting spot that were arranged in a triangular pattern, approximately 3 feet apart. The immediate plot area was scalped at planting time. Water was metered from 0.5- and 1-gallon plastic containers fitted with 1-gallon/hour drip irrigation fittings. Water was applied monthly from June to September 1994. Height and survival sampling dates are show in *figure 3*.

1994-1995 Activities

The regeneration test and irrigation study sites were replanted in early February 1995 with germinating acorns from either Poly Canyon or Pleasanton. Litter was replaced as before; however, no rescalping was done. Plant cover in the scalped areas was mostly scattered filaree (*Erodium* spp.) and was not considered a serious competitor of the oak seedlings.

Data Collection and Analysis

Treatment results for all 4 years of the work reported here are based on seedling height and survival measured periodically throughout the summer and fall (*figs. 1* to *3*). Seedling height was based on the height of the tallest live seedling per planting spot. The final evaluation for each planting cycle was usually obtained after December, with the exception of 1994-1995 when the last measurements were made in early December.

Survival data for the Regeneration Test were analyzed by logistic regression (SAS) that expressed probability of survival as a nonlinear function of age and treatment variables, with the control treatment as a reference. Height data were analyzed by multiple regression (MINITAB), again controlling for age. Plot replication differences were evaluated by a two-way analysis of variance.

Results

Regeneration Test

Seedling survival for the control and three treatments for the entire 4-year planting effort is shown in *figure 1*. Seedling emergence for the 1991-1992 cycle did not peak until mid-July for all treatments except the controls, whose survival had already begun to decline and continued to do so until replanting in 1993.

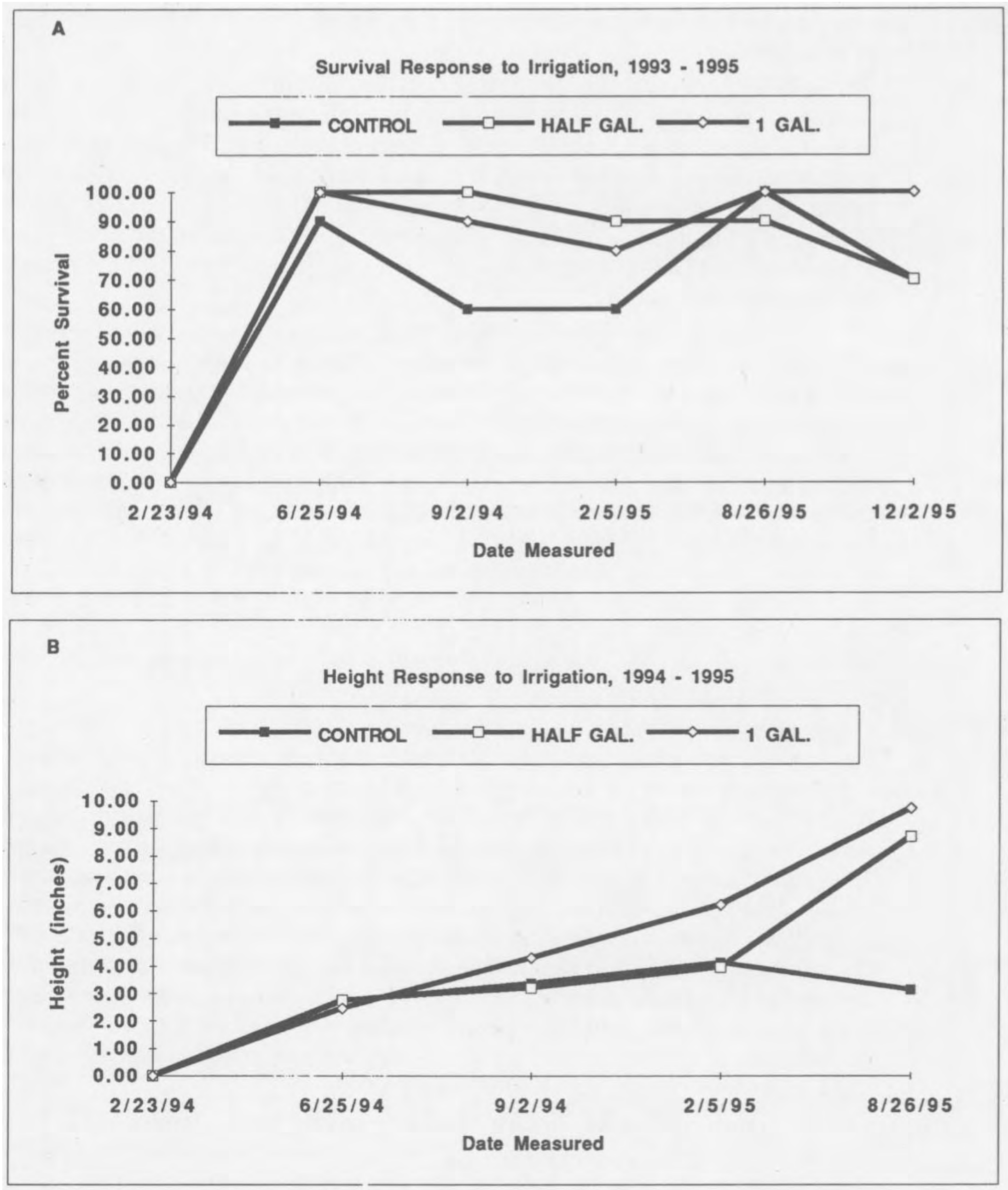

Figure 3—Percent survival (A) and average height (B) of coast live oak seedlings for the Irrigation Study 1994-1995 planting cycles. Monthly irrigation from June to October enhanced seedling height over the nonirrigated seedlings, but the effect of irrigation on seedling survival was not clearcut.

Emergence was relatively poor for all treatments, ranging from 42.9 percent for the controls to 62.9 percent for the tree shelters.

Seedling survival for the tree-shelter treatments remained constant until September 1; then there was a dramatic decline to only 14.3 percent by January 1, 1993. During this time, seedling survival for the litter treatment slowly declined, and by January 1993, it had dropped to 37.1 percent. The tree shelters initially stimulated modest height growth (*fig. 2*) over that obtained with the control and litter treatments. The high seedling mortality after September 1 did not change the height relationship among treatments. Extensive pocket gopher activity was present throughout the test area, but no seedling death was attributed to them. Most of the control and litter treatment seedlings showed signs of herbivory, and many of the tree shelter seedlings were infected with woolly aphids (*Stegophylla quercicola* Baker).

Seedling survival for the 1992-1993 cycle, which included surviving seedlings from the 1991-1992 cycle, was much higher than it was for the previous year, ranging from 80.0 to 91.4 percent on July 22. Planting in January and above-normal winter rainfall may have accounted for the increased level of survival that was enhanced by the surviving 1991-1992 seedlings. Again, there was a big decline in seedling survival for all treatments during the fall and winter (*fig. 1*). However, the seedlings in the tree shelters still maintained their height dominance.

The survival pattern for the 1993-1994 planting cycle was similar to that for 1992-1993, and 85 to 95 percent of the planting spots had live plants on June 15, 1994, except the litter treatment with only 71.4 percent. The pattern of survival was also very similar to that for 1991-1992 with a large decline after September 2. However, minimal seedling survival ranged from 48.5 to 71.4 percent, much higher than for the 1991-1992 cycle. By this time, average seedling height for the two tree-shelter treatments was about double that for the control and litter treatments and ranged from 9.0 to 10.5 inches (*fig. 2*) for the shelter and shelter-plus-litter treatments, respectively. Pocket gopher activity continued, and a few planting spots were almost completely surrounded by exit holes, but no seedling mortality was attributed directly to gophers. Most unprotected seedlings had some browsing. An extremely heavy infestation of grasshoppers was present all summer.

Seedling survival and height were measured only twice in 1995. The August 26 sampling was probably too late to obtain maximum seedling establishment, but the percent survival was still very high for both shelter treatments, ranging from 91.4 to 97.1 percent. Survival for the control and litter treatments was somewhat lower at 68.5 and 77.1, respectively. Seedling age at the beginning of 1995 varied from 1 to 3 years. However, most seedlings had died (replanting required) or were 2 years old. Logistic regression analysis indicated that seedling age, but not treatments, was a significant predictor of seedling survival ($P \leq 0.01$). Again, a major decline in seedling survival occurred after early September for the shelter treatments. Although 31 of the 70 tree-shelter seedlings were infested with woolly aphids, only three of the infected seedlings died after August 26. The amount of gopher activity was amazing. In some areas on and around the test site, exit holes were only 6 to 10 inches apart.

Average height for seedlings in the shelter-plus-litter treatment also declined because some of the seedlings that died were 2 years old and more than 40 inches tall. However, seedlings for both tree-shelter treatments were about twice as tall as the control and litter seedlings. There was no significant difference between shelter treatments, or between the control and litter treatments. An ANOVA of the replications indicated that there was no significant plot effect ($P \leq 0.05$).

Irrigation Study

Seedling survival for the 0.5- and 1.0-gallon irrigation treatments ranged from 80 to 100 percent for the entire test, except for a decline to 70 percent for the 0.5-gal. rate on the last sampling date in December 1995. Average percent survival for nonirrigated seedlings was generally less than for those that were irrigated (*fig. 3A*). Irrigation had a positive effect on seedling height, but there was no apparent difference between irrigation levels (*fig. 3B*).

Discussion

Attempts to artificially regenerate coast live oak in the Central Coast area of California have generally not been successful for the past several years (Plumb and Hannah 1991). Initial establishment has been excellent on some exposed grassy sites, but few coast live oak seedlings were alive 2 years later. Excluding damage and death by the many types of herbivory that have been reported on oaks, lack of coast live oak seedling survival can generally be attributed to unsatisfactory site conditions and to moisture stress specifically.

The study area had nearly uniform soils in and out of the oak stand and seemed like an ideal location to test some promising regeneration techniques. The natural expansion of the adjacent coast live oak stand over the past 80 years and the presence of advanced regeneration on the site indicated that this should be a suitable location to establish coast live oak. It was hoped that moisture stress from grass competition and low rainfall would have been counteracted by weed control, oak mulch, and/or irrigation.

Pocket gophers were a serious threat during the study, especially in 1995. The buried chicken wire exclosures seemed to provide adequate protection for the seedlings. The death of only a few seedlings could be directly attributed to gophers, and these were seedlings which gophers had extensively excavated around a planting spot. The potential threat to unprotected seedlings and advanced regeneration was demonstrated on the test site in August 1995 when a natural seedling at least 5 to 10 years old and 0.6 inches in diameter at ground level was completely severed a few inches below ground. The damage appeared to be exactly like that described by Lathrop and Yeung (1991) for Engelmann oak (*Q. engelmannii* Greene) and shows the need for long term protection where gophers are present. Unprotected seedlings have little chance of escaping gopher herbivory.

Tree shelters are used to promote height growth and reduce herbivory (Costello and others 1991, Manchester and others 1988). Both of these effects were obtained in this project. And, both tree-shelter treatments significantly enhanced average seedling height after 4 years of replanting (*fig. 2*). To the contrary, seedling survival was not enhanced by the shelters. Each year, there was a major decline in seedling survival in the fall. Ironically, the shelters produced the biggest seedlings and the lowest survival. What went wrong? Woolly aphids infested many of the these seedlings, but they usually do not cause plant death (Brown and Eads 1965). The micro environment in the shelters, which can be at least 4 to 7 °F warmer than the outside air (Costello and others 1991), apparently favored the aphid infestation.

Moisture stress would seem to be the obvious explanation for the fall seedling deaths. Irrigation was usually discontinued after September; this may have been too soon and watering probably should have been tailored to fall precipitation. Although early fall precipitation occurred in 1994, still many seedlings died during the fall and early winter. Were these deaths due to moisture stress or something else? The tree shelters promoted accelerated growth that may have ultimately contributed to the seedling deaths because of their greater water requirements.

The effectiveness of the irrigation methods was somewhat suspect because of the erratic discharge from the plastic containers and the variable amount of surface runoff that occurred from one seedling to another with hand watering. Using plastic containers in 1995 with drip emitters eliminated both of these problems. Other studies indicate mixed results with supplemental irrigation (Costello and others 1991, Gordon and others 1991), and Swiecki and Bernhardt (1991) even suggested that irrigated plants are more likely to be browsed than non-irrigated plants. In the irrigation study reported here, providing monthly amounts of either 0.5 or 1.0 gallon of water per seedling greatly enhanced height growth over that for the non-irrigated control plants (*fig. 3*). The effect of irrigation on survival was less obvious, though it was deemed to be worthwhile.

The effect of oak mulch to reduce moisture stress was not clearcut, although it did appear to enhance seedling survival at the end of the 1991-1992 and 1994-1995 planting cycles. Both Davis and others (1991) and Adams and others (1992) note the negative impact of annual grass on seedling survival. Controlling competing vegetation through a variety of methods, including scalping and mulching, can greatly improve the survival of planted seedlings (McCreary 1991). Because both scalping and oak leaf mulch were used in this test, the overall effect of scalping may have masked the effect of the mulch.

Finally, replanting this site for 4 consecutive years did not result in complete stocking. Although the overall percent survival for all treatments increased from 21.4 percent for the first planting cycle to 69.3 percent for the fourth planting cycle, this was only 7.9 percent higher than the overall survival at the end of the second planting cycle. The only significant factor affecting survival after 4 years was seedling age where the odds of survival were directly related to seedlling age (ln value of survival = 0.839 + 0.693 age). It seems reasonable to expect that seedlings that survived for 1 or more years would have a better chance of persisting another year than would a crop of new seedlings.

Conclusions

This work demonstrated that it can be extremely difficult to attain 100 percent survival (stocking) of coast live oak on a promising field site, even after repeated replanting. Little increase in stocking was gained after the second planting. It would be fiscally imprudent to repeat replanting until the cause of the late-fall, early-winter seedling death was identified.

Tree shelters enhanced coast live oak seedling growth and effectively prevented herbivory, but they did not promote greater seedling survival on this site. Late-fall, early-winter seedling death appeared to be related to moisture stress. Irrigation that was either more frequent, at a higher rate, or later in the fall might have prevented this decline in survival. Also, planting in 6- to 8-inch diameter shelters might have provided a better micro environment for the seedlings as they appeared to be crowded in the 3.5-inch diameter shelters used in this test.

Finally, although some natural seedlings near the test site have persisted and developed into saplings, it is not clear how they made it. To ensure satisfactory survival of artificial regeneration of coast live oak, we do know that it is essential to protect seedlings from above and below ground herbivory, but we are not yet certain about the level of irrigation that is needed or if irrigation is needed at all.

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