Effects of Shade on Blue Oak and Coast Live Oak Regeneration in California Annual Grasslands[1]

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Abstract: Canopy effects and annual vegetation have been shown to strongly influence oak seedling survival. From the many elements composing canopy, shade was selected for experimental manipulation. A split-plot, multifactorial experiment was designed to test whether blue oak (*Quercus douglasii*) and coast live oak (*Q. agrifolia*) could establish seedlings in annual grasslands outside of canopy influence, and if there were differences in the responses of the two species to shade and sun treatments. All herbivory was excluded from three plots. All plots were constructed outside of direct canopy influence, and the annual herbaceous vegetation was not manipulated. Even under conditions of prolonged, severe drought, blue oaks and coast live oaks were able to establish seedlings from acorns in annual grasslands. Although the initial emergence of coast live oak seedlings from acorns was greater than that of blue oak in the first year, more blue oak seedlings were alive a year later. The survivorship of both species was significantly enhanced by the shade treatment.

The statewide oak regeneration survey concluded that in many locations, regeneration was inadequate to maintain existing stands. Additionally, the occurrence of regeneration was considered highly site specific. Seedlings of blue oak (*Quercus douglasii)* and coast live oak (*Q. agrifolia*) occupied the canopy understory quite successfully. Yet taller, sapling-sized blue oaks were rarely located under tree canopies and were found on the edge of the canopy and in the open. In contrast, coast live oak seedlings and saplings were both found beneath tree canopy (Muick and Bartolome 1987).

During the survey and subsequent field work I observed another phenomena. Evergreen oak species—coast live, interior live (*Q. wislizenii*), and canyon live (*Q. chrysolepis*)—appeared to be regenerating more successfully throughout the state. In certain locations live oak saplings, which looked like maiden trees rather than stump sprouts, were growing under the canopy of mature blue oak stands. The presence of live oak saplings, plus the absence of deciduous oak saplings, suggested that locally important changes in oak woodland species composition were taking place.

Shade tolerance is a term, most commonly used by foresters, to describe the relative ability of a species to grow and thrive under a forest canopy. A tolerant species can grow and thrive under tree canopy, whereas an intolerant species can thrive only away from the main canopy or in the open. The major canopy effect limiting species in arid environments is thought to be reduced soil moisture; light is rarely limiting in temperate forests (Spun: and Barnes 1980). Sudworth (1908) described coast live oak as highly tolerant of canopy condition and blue oak as highly intolerant. Based on data, observations, and relative tolerance ratings, I hypothesized that blue oaks were unable to grow to sapling size under tree canopy.

In evaluating the effects of canopy, I considered the relationship between canopy and shade. The effects of shade and tree canopy are best considered as overlapping, but not equivalent, variables. Tree canopy intercepts solar irradiance resulting in a zone of reduced light beneath and around the tree. However, shade is only one of several components comprising canopy effects.

The effects of canopy include other attributes besides reduced light. Soil moisture, nutrient status, soil texture, and pathogens are usually quite different beneath a tree than in a comparable site without tree cover. Shade itself is variable, and depends upon the amount of light blocked, and areal, daily, and seasonal patterns. Although tree canopy may be a dominant source of shade in oak savannas and woodlands, shade can also result from topographic relief, rock outcrops, and shrubs and herbaceous vegetation.

At the Sierra Field Station, Momen (1987) evaluated the effects of canopy on water potential of blue oak seedlings in grazed and ungrazed locations. The lowest values of seedling water potential occurred in grazed areas beneath tree canopy, which also had the higher densities of annual grasses. Momen concluded that the prospect of blue oak seedling survival is greater in the grazed, open environment than beneath canopy.

Cruzan (1981) found that all coast live oak seedlings growing in the full sun died. In the shade and vegetation removal experiments, increased shade and/or decreased annual vegetation led to higher percentages of seedling survival. The negative effects of annual grass and forb species on oak seedling survival have been reported by many authors (Griffin 1980, Welker and Menke 1987, Gordon and others, 1989).

Other researchers have tested the effects of herbivore exclusion (Borchert, and others 1989) and compared the effects of canopy with non-canopy areas (Momen 1987, Welker and Menke 1987). To date no California researchers have tested blue oak canopy components away from the canopy environment. Therefore I decided to manipulate a single effect of the canopy, shade, while holding annual vegetation, seed source, and rodent populations constant. For the purposes of this study, shade can be considered as either a canopy effect or a variable independent of canopy.

This paper reports on my investigations to determine 1) if blue oak and coast live oak could establish in annual grasslands

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outside of canopy influence, and 2) if, at the seedling stage, the species exhibited different responses to shade or sun outside of canopy influence. The experiments were carried out in exclosures which protected the seedlings from all vertebrate herbivores. Vertebrates have been demonstrated to consume both acorns and seedlings in many locations (Borchert and others 1989, Griffin 1980).

THE EXPERIMENT

Field experiments were conducted at the Hastings Natural History Reservation, Carmel Valley, Monterey County, in the Inner South Coast Ranges. At Hastings I selected three annual grassland sites, formerly "old fields", each within about 10 meters of an existing oak stand. Sites were located at similar elevations but on different soils representing a spectrum of Hastings' soil types. Robertson Saddle (2) is the most arid site and also receives the most insolation. Tire Flat (3) is the most mesic site and receives the least insolation. North Field (1) is mid-way between the other two sites in terms of insolation, but is more similar to Tire Flat in terms of soil type and moisture.

In order to eliminate the influences of vertebrate herbivores, exclosures were thoroughly fenced, both above and below ground. A backhoe was used to dig a trench around a rectangular area measuring approximately 6 meters by 8 meters. Trenches were excavated to a thick, claypan that was considered to define the lower limit for burrowing rodents. Depth to claypan varied across the plots and ranged from 1 to 3 meters. During construction and fence building, soil disturbance and compaction on plot surfaces was minimized. Most of the rodents remaining within the plot after construction were removed by trapping. The top of the exclosure was not fenced. Exclosures were rested for about one year and the plots were planted in December, 1988.

I used a split-plot, multifactorial experimental design. Each 6 m by 8 m exclosure plot was divided into four quarters of similar size, with buffer strips defined between plots and next to the fences. Two diagonally opposed quarters were assigned to the shade treatment, while the other two were unshaded and served as controls. An evenly spaced grid of sixteen cells, each cell measuring about 30 cm on a side, was superimposed on each quarter-plot. Species and treatments were assigned to each cell according to a pre-determined, interspersed random pattern. The 16 acorns in each cell were from the same parent tree, in the case of blue oak, or from the same population, in the case of coast live oak.

Planting was accomplished by wedging the soil open with a trowel, then dropping an acorn, sideways, into the 5 to 7 cm deep crevice. The opening was closed and about 100 ml of water was poured over each spot after planting. All acorns were planted within two days in December of 1988.

For the shade treatment shadecloth tarps were positioned over the two shade treatment quarter plots, in each of the three exclosures, in February of 1989. The six tarps were sewn from shadecloth which was rated to block out 50 pct of overhead sunlight (®Weathashade). Each tarp was suspended horizontally, about 1 to 1.25 meters above the ground, and three corners were fastened to the exclosure fence. The fourth and inside corner of the tarp was attached to a fencepost driven into the middle of the plot.

Data were collected monthly. I counted the number of seedlings emerged and alive, calculated average number of leaves and stems, and measured the height of seedlings and annual vegetation. I also noted and quantified other data including evidence of arthropod herbivory.

RESULTS

The following results are based on the emergence and above ground mortality data. Emergence was defined as the presence of a shoot or stem with leaves by June 1989. Survival was defined as the presence of a stem with green leaves or a green stem, in June 1990. The responses of the seedlings varied

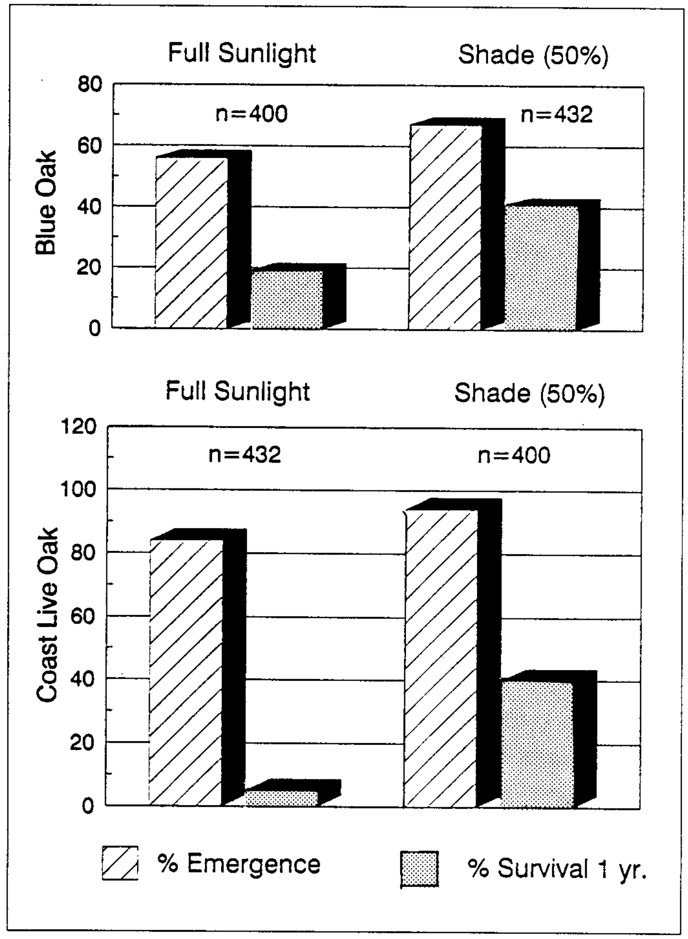

Figure 1—A graph of emergence and survival of blue oak and coast live oak seedlings by treatment.

between plots, however, several general and significant patterns emerged (figure 1).

Emergence and Survival by Species

A very high percentage of coast live oak, on both sun and shade plots, emerged (table 1). Of the 832 acorns planted in December of 1987, 739 (89 pct) had emerged by June of 1989. However, a year later in June of 1990, the population of coast live oak seedlings had decreased dramatically. Only 181(22 pct) coast live oak seedlings survived and of those 89 pct (all but 20) were found under the shade treatment.

Only 515 (62 pct) of the 832 blue oak acorns produced an above-ground stem by June 1989. However, a year later in June 1990, 30 pct of those planted or almost half of those that had emerged were alive. Of the 251 surviving blue oak seedlings 75 pct were located under the shadecloth.

Patterns of Emergence and Survival

Coast live oak acorns gave rise to many more seedlings than did blue oak acorns. Using two-way analysis of variance (ANOVA), species and seedling emergence were significantly related ($p= 0.05$). This may well be related to differences in viability between the two species.

Shade treatments were strongly and significantly related to seedling survival ($p= 0.05$). On the extremely arid Robertson Saddle plot, only 2 (3 pct) of the previous year's blue oak seedlings and 1 (1 pct) of the previous year's coast live oak seedlings leafed out, all under the shadecloth. On the two more mesic plots, North Field and Tire Flat, greater numbers of blue oak seedlings survived on the sun plots, 32 pct and 26 pct respectively. There was no significant difference between species in their response to the treatments.

DISCUSSION

Shade tolerance of a species can vary over the lifetime of a plant and between individuals. Black oak (*Q. kelloggii*) can persist in the understory for many years, but in order to reach maturity it must have its canopy in the sun (McDonald 1978). Although Sudworth characterized blue oak as highly intolerant, results presented here suggest that blue oak does display some tolerance to experimentally produced shade at the seedling stage. Other authors (Momen 1987 and Welker and Menke 1987) also mention the presence of naturally occurring blue oak seedlings under tree canopy.

The mean annual precipitation at Hastings is 535 mm (21 inches), which usually falls as rain and occasionally as snow during the winter months. As the record shows, drought is not an uncommon event at Hastings (figure 2). In the previous 62 years precipitation was below average thirty-six or 58 pct of the time. Precipitation measured less than 400 mm (15.7 inches) for thirteen of those below average years. During this study, Hastings was undergoing the second and third years of an extreme drought, and precipitation has been below 14 inches annually since the 1987-88 season. Rainfall during 1987-88, the year prior to planting, was 347 nun (13.7 inches). Rainfall during the 1988-89 season, when seedling emergence was counted, was only 328 mm (12.9 inches). Precipitation during 1989-90, the year survival was observed, measured 347 mm (13.7 inches).

No additional water was brought onto the plots after the 100 ml poured over each acorn seed spot at the time of planting in December, 1987. The effects of the shadecloth tarp on the accumulation of additional condensation is unknown; however, snow and fog are uncommon at Hastings.

The high levels of moisture stress measured on blue oak seedlings growing under tree canopy (Momen 1987) and high percentages of seedling mortality measured by Welker and Rice (1987) suggest this a one possible mechanism for the exclusion of blue oak saplings from the beneath the canopy environment (Muick and Bartolome 1987). The strong **positive** relationship between shade and blue oak seedling survival as presented in this study suggests that blue oak regeneration may be enhanced

Table 1—*Summary of seedling emergence and survival by species and treatment.*

Planted in Species	Acorns in 12/1988	Seedlings Emerged Surviving in 6/1989		Seedlings Surviving 1.5 Years 6/1990		Overall Survival 1988-1990
	No.	No.	Pct	No.	Pct	Pct
Blue oak						
FULL SUN	400	222	56	74	33	19
SHADE	432	290	67	177	61	41
Total	832	512	62	251	49	30
Coast live oak						
FULL SUN	432	363	84	20	6	5
SHADE	400	376	94	161	43	40
Total	832	739	89	181	25	22

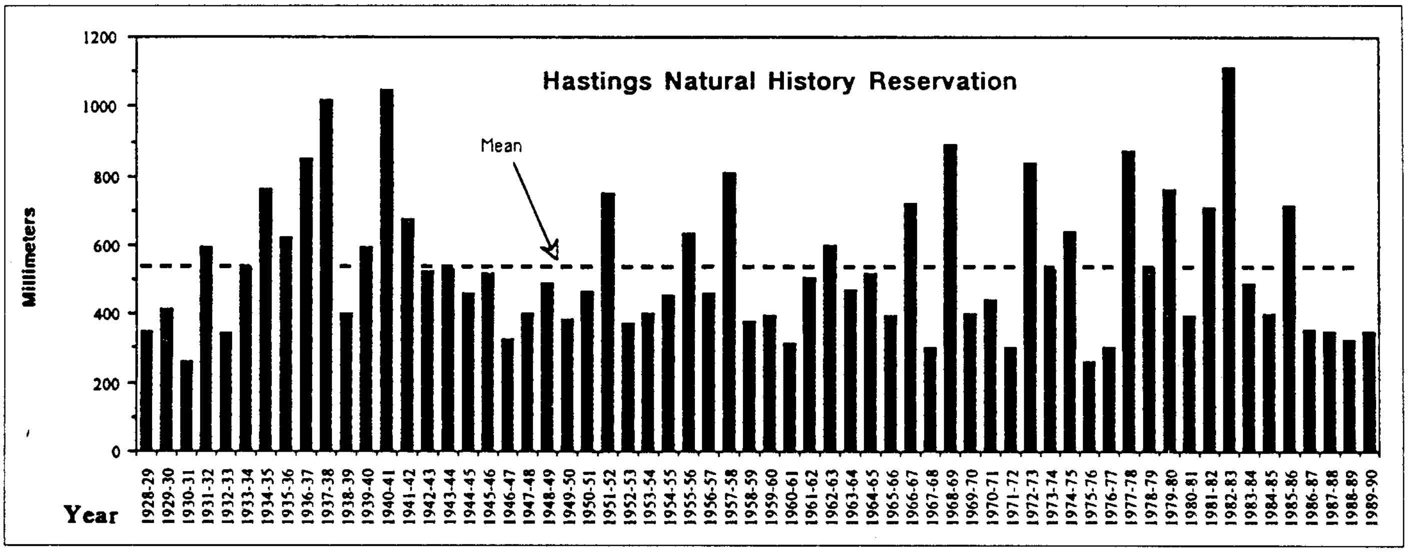

Figure 2—Total annual precipitation measured at Hastings Natural History Reservation: 1928-1990.

by shade. This suggests that one quality of a blue oak regeneration site is non-canopy shade. It may well be that the least likely location for successful blue oak regeneration to occur is under tree canopy.

CONCLUSIONS

Naturalized annual grasses and forbs are frequently associated with the lack of oak regeneration, particularly for blue oaks (Gordon, and others 1989, Welker and Menke 1987). However, even under conditions of prolonged, severe drought, blue oak and coast live oaks were able to establish seedlings from acorns in annual grasslands, when protected from vertebrate herbivory. Both oak species were able to successfully establish seedling populations, based on shoot emergence in the first year. Coast live oak required shade for seedling survival into the following year whereas blue oak seedlings survived on both sun and shade plots. Blue oak survivorship was significantly enhanced by the shadecloth treatment, and blue oak seedlings survived in greater numbers than coast live oak.

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