Stand-Level Status of Blue Oak Sapling Recruitment and Regeneration[1]

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*Abstract: We assessed blue oak (*Quercus douglasii*) sapling recruitment and regeneration at 15 locations distributed throughout the range of blue oak. Overall, 15.3 percent of the 1500 plots surveyed contained blue oak saplings. Four locations had moderate numbers of saplings, and the remaining locations had few to no saplings. Seedling-origin saplings were far more common than stump-sprout saplings. Most saplings were shorter than the browse line (1.4 m). At 13 of the 15 locations, sapling recruitment is inadequate to offset recent losses in blue oak density and canopy cover.*

There is a widespread belief that blue oak (*Quercus douglasii* Hook. & Arn.) is not regenerating well over much of its range. Several researchers have shown that flushes of blue oak recruitment coincided with the influx of settlers into California in the period from the 1850's through the 1890's (McClaran and Bartolome 1989, Mensing 1992, Vankat and Major 1978), but that little recruitment has occurred in the latter half of this century. Data from two surveys (Bolsinger 1988, Muick and Bartolome 1987) have been interpreted to indicate that blue oak sapling populations are insufficient to maintain current stand densities. However, these surveys do not provide a clear picture of recent recruitment, because they include blue oaks up to 12.7 cm diameter at breast height (DBH) in the sapling size class. Oaks of diameters approaching 12.7 cm are functionally in the tree size class and could easily range from 30 to more than 90 years old (McClaran 1986).

We conducted a study to examine the distribution of small blue oak saplings at the stand level and assess net blue oak regeneration in these stands. We studied oaks in the transitional stage between seedling and small-diameter tree, during which height growth can be limited by browsing animals. No previous surveys of California oak woodlands have focused on oaks in this size class. We sampled many plots spread over a large area in each stand to determine how sapling recruitment and regeneration are distributed at the landscape level. Previous blue oak surveys are based on data collected from single plots or clusters of up to five subplots at widely separated locations (Bolsinger 1988, Muick and Bartolome 1987) and do not show how saplings are distributed at the stand or landscape level. Additional results of this project are presented elsewhere (Swiecki and others 1993, Swiecki and others, these proceedings).

Methods

We selected 15 locations, geographically stratified throughout the range of blue oak, for study (*table 1*). Candidate study locations had to have at least 61 ha of mostly contiguous woodland dominated by blue oak and a known history of grazing, fire, clearing, and other management practices for the 30 years before 1992. Clearing history had to be extended back 42 years because of uncertainty about when tree cutting occurred at one of the locations. We selected locations without prior knowledge of the amount of sapling recruitment present.

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Table 1—Blue oak seedling-origin recruitment by location

Location		County	Live seedling-origin saplings (pct of plots)	Dead seedling-origin saplings (pct of seedling-origin saplings)	S0 seedlings[1] present (pct of plots)
1	Wantrup Wildlife Sanctuary	Napa	31	2	33
2	Black Butte Lake	Glenn	0	—	0
3	Pinnacles National Monument	San Benito	40	8	30
4	Sierra Foothills Research & Extension Center	Yuba	39	21	23
5	Hopland Field Station	Mendocino	0	—	0
6	Sequoia National Park	Tulare	13	5	10
7	Dye Creek Preserve	Tehama	15	21	1
8	Pardee Reservoir	Amador	3	14	1
9	Pozo (private ranch)	San Luis Obispo	8	45	1
10	Lake San Antonio	Monterey	15	27	0
11	Hensley Lake (private ranch in part)	Madera	0	—	0
12	Henry W. Coe State Park	Santa Clara	0	—	1
13	Mt. Diablo State Park	Contra Costa	2	25	1
14	California Hot Springs (private ranch)	Tulare	5	40	0
15	Jamestown (private ranch)	Tuolumne	19	3	13

[1]Presapling seedlings—plants at least 25 cm tall with a basal diameter of less than 1 cm.

For each location, we used aerial photography, vegetation cover maps, and topographic maps to determine the portion of each study location that was dominated by blue oaks. We designated sample plot locations by superimposing a rectangular sampling grid over a map of the area, placing the origin of the grid at a randomly selected starting point. We oriented the grid along the four cardinal directions in a predetermined order and selected the first orientation that provided at least 100 plots in areas dominated by blue oak. If no orientation met these criteria, we selected a new random point and repeated the process.

The sampling grid included an area 1,520 m by 900 m (136.8 ha). Plots in the grid were arranged in 10 parallel transects spaced 100 m apart. Plot centers within transects were spaced 80 m apart. The grid provided 200 plot locations, at a density of one plot per 0.8 ha. We selected this plot spacing to minimize the possibility that recruitment in one plot would directly affect the likelihood of recruitment in an adjacent plot.

We surveyed 1,500 plots between July and early November of 1992. At each location, we started at the first accessible plot on the grid and surveyed plots sequentially along the transects, skipping ineligible or inaccessible plots, until we had collected data from 100 plots. Deviations from the target sample size occurred only at Pinnacles (99 plots) and Sierra (101 plots). Plots were considered ineligible for sampling if they were more than 80 m from the nearest blue oak. We navigated between plots using a compass and an optical rangefinder, and ground positions were verified through the use of topographic maps, aerial photos, and a Global Positioning System (GPS) receiver (Garmin GPS 100 SRVY) operating without differential correction.

Plots were circular, with a 16-m radius and an area of 0.08 ha. In each plot, we counted the number of dead and live blue oak saplings and classified each sapling by size class and origin class, either seedling-origin or sprout-origin. We inspected the base of each sapling and designated saplings as sprout-origin if they arose from stumps or topkilled trees with a basal diameter of at least 8 cm.

We also noted the position of each sapling relative to tree canopy (open, canopy edge, under canopy).

We defined saplings as oaks with a basal diameter (BD) of at least 1 cm and no stem with a DBH (diameter at 140-cm-height) of more than 3 cm. Sapling size classes we used were:

Sapling size class:	Size range
S1	BD≥1 cm, <140 cm tall
S2	BD≥1 cm, ≥140 cm tall, DBH <1 cm
S3	BD≥1 cm, DBH 1-3 cm

S1 saplings are subject to loss of the shoot leader because of browsing by large herbivores such as cattle and deer. S2 saplings have at least one shoot that is above the nominal browse line, but such shoots are still small enough to be damaged or destroyed by large herbivores. Saplings in the S3 size class are unlikely to have their height growth constrained by browsing animals and have a high probability of advancing to the tree size class.

We defined a pre-sapling seedling class (S0 seedlings) as plants that were at least 25 cm tall but had a basal diameter of less than 1 cm. Seedlings in this size class are generally visible throughout the year, whereas smaller seedlings are not (Swiecki and others 1990, 1993). In each plot, we rated the abundance of S0 seedlings using a count class scale: 0, 1 to 10, 11 to 20, 21 to 30, 31 to 40.

Within plots, we counted the number of live blue oak trees (DBH > 3 cm) and noted if the trees appeared to be of sprout origin. We also counted blue oak snags, downed trees, and stumps which appeared to have died in the 30 years before 1992. Bark presence and condition and degree of decay were used to determine the likely number of years since mortality, and site history records were used to verify field evaluations where possible. For plots in which blue oak mortality occurred, we noted the position of the dead tree relative to other trees in the plot and recorded whether the mortality caused a decrease in blue oak canopy cover and/or created a canopy gap. For example, if a blue oak tree overtopped by another tree species dies, blue oak canopy cover is reduced, but no canopy gap is created.

Results

Sapling Recruitment by Origin Class, Canopy Position, and Size Class

We observed seedling-origin saplings at 11 of the 15 study locations (*fig. 1*) and tallied 1,326 live and dead seedling-origin saplings in a total of 207 plots. Although Wantrup had the highest number of seedling-origin saplings, Pinnacles and Sierra had seedling-origin saplings in the greatest percentage of plots (*table 1*). Seedling-origin saplings were most likely to occur beyond overstory canopy or at the canopy edge at these three study locations (*table 2*).

We observed sprout-origin saplings at seven of the study locations (*fig. 2*) and tallied 182 live and dead sprout-origin saplings in a total of 33 plots. Nearly

Table 2—*Percentages of live blue oak seedling-origin S1-S3 saplings in each position relative to the canopy for the three study locations with the most saplings*

Location	Count of seedling-origin saplings	Position relative to canopy (pct of total)		
		Open	Edge of canopy	Under canopy
Wantrup	823	68	25	7
Pinnacles	162	69	24	7
Sierra	119	50	29	22

Figure 1—Total numbers of live blue oak seedling-origin saplings in plots at each location by size and origin class. Location numbers are as in table 1. S1, S2, and S3 sapling size classes are described in the Methods.
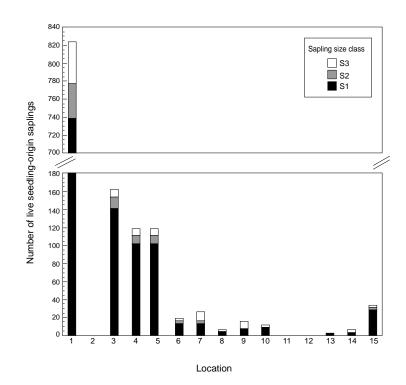

Figure 2—Total numbers of live blue oak sprout-origin saplings in plots at each location by size and origin class. Location numbers are as in table 1. S1, S2, and S3 sapling size classes are described in the Methods.
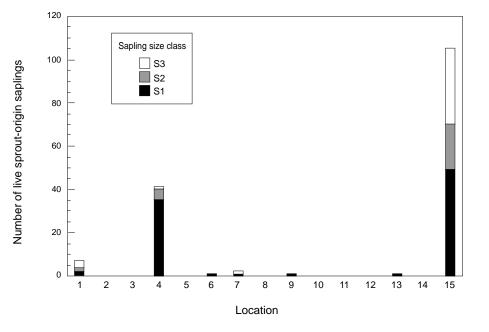
Table 3—Occurrence of sprout-origin blue oak saplings and trees by location

Location	Trees cut within the past 42 years (pct of plots)	Live sprout-origin saplings (pct of plots)	Dead sprout-origin saplings (pct of sprout saplings)	Live sprout-origin trees (pct of live trees)
Wantrup	63	3	53	1
Black Butte Lake	4	0	—	1
Pinnacles	6	0	—	3
Sierra	16	7	7	12
Hopland	3	0	—	4
Sequoia	0	1	0	2
Dye Creek	2	1	0	5
Pardee Reservoir	0	0	—	6
Pozo	5	1	0	3
Lake San Antonio	4	0	—	7
Hensley Lake	0	0	—	15
Henry Coe	5	0	—	2
Mt. Diablo	0	1	0	3
California Hot Springs	10	0	—	11
Jamestown	35	17	11	33

all of the sprout-origin saplings were located in the open, beyond tree canopy. Most locations had recent tree cutting in at least some plots, but sprout-origin saplings were generally scarce (*table 3, fig. 2*). Only Sierra and Jamestown had sizable numbers of sprout-origin saplings, and only at Jamestown did sprout-origin saplings outnumber seedling-origin saplings (*figs. 1, 2*). Jamestown also had the largest percentage of sprout-origin trees. Some of the sprout saplings at Jamestown originated from stumps of these sprout-origin trees.

We found many stumps from both recent and older cuttings that had failed to produce sprouts. In at least one area, the lack of stump sprouting was associated with severe sapwood decay of stumps.

The majority of all saplings were in the S1 size class (*figs. 1, 2*). Most saplings in the S1 size class were much shorter than 140 cm tall. S1 saplings were usually highly branched and shrubby in habit. Most lacked a distinct leader, because of repeated browsing of the shoot tips. In contrast, virtually all S3 saplings and most S2 saplings had one or two dominant vertical shoots.

Among the 190 plots with live seedling-origin saplings, 43 percent had only a single seedling-origin sapling present, 22 percent had five or more, and 8 percent had 20 or more. The maximum number of live seedling-origin saplings per plot was 207. Among the 31 plots with live sprout-origin saplings, 42 percent had only a single sprout-origin sapling present, and 34 percent had five or more. Ten plots had both live seedling-origin and sprout-origin saplings.

We tallied at least one dead sapling at every location where live saplings were present. The percentages of dead saplings observed varied widely by location (*tables 1, 3*) and were not correlated with the total number of saplings per location. Overall, 6.9 percent of the seedling-origin saplings and 13.2 percent of the sprout-origin saplings we observed were dead. Of the plots with saplings, 6.9 percent contained only dead saplings. Many of the dead S1 saplings were in open positions and were stunted by repeated browsing. In contrast, mortality of the S2 and S3 size classes was often associated with overtopping by adjacent trees.

Seedlings in the S0 size class were found in at least one plot at 10 of the 15 study locations (*table 1*). The four locations with the highest incidence of S0 seedlings also had the greatest number of plots with seedling-origin saplings. In most cases, only a single S0 seedling was found in a given plot, but four plots at Wantrup had more than 20 S0 seedlings.

Tree Mortality and Net Regeneration

Overall, nearly 6 percent of the blue oak trees found within plots were judged to have died from causes other than cutting over the period 1962-1992 (*table 4*). Assuming that our estimated dates of mortality did not vary by more than ±10 years for the 30-year period, the overall rate of natural mortality observed for all locations was about 2 percent (1.5–3 percent) per decade, or between 1.6 and 3.2 deaths/ha/decade. Henry Coe had the highest estimated rate of mortality, between 2.7 and 5.4 percent per decade, or 3 to 6 deaths/ha/decade. The low percentage of dead trees at Hensley Lake is in part due to the prompt removal of dead trees by the landowner of the ranch portion of the location.

Table 4—Shrub frequency, blue oak density, and mortality by location

Location	Shrubs present (pct of plots)	Blue oak trees present (pct of plots)	Only blue oak trees in canopy (pct of plots)	Average blue oak density (live trees/ha)	Dead blue oak trees (pct)	Natural blue oak tree mortality (pct of plots)	All blue oak mortality[1] (pct of plots)
Wantrup	52	82	24	159	4	23	49
Black Butte Lake	2	85	85	98	4	23	25
Pinnacles	85	78	35	71	5	23	23
Sierra	83	88	6	161	2	18	24
Hopland	23	76	30	99	7	33	33
Sequoia	79	99	29	157	5	47	47
Dye Creek	16	86	80	113	6	37	38
Pardee Reservoir	12	80	58	38	10	26	26
Pozo	23	83	61	135	8	46	46
Lake San Antonio	77	86	35	101	5	28	28
Hensley Lake	3	66	65	16	3	4	4
Henry Coe	80	81	4	113	11	42	42
Mt. Diablo	44	82	35	150	6	41	41
California Hot Springs	44	94	31	128	8	50	50
Jamestown	50	67	19	59	3	7	32

[1] Includes both natural mortality and stumps originating from trees cut between 1950 and 1992.

As an estimate of net regeneration at each location, we compared blue oak sapling recruitment with total tree mortality within each plot. We made the simplifying assumptions that every live sapling represents a potential tree, and to maintain stand density, one live sapling was needed to offset each tree that had died within the past 30 years or had been cut within the past 30 to 42 years. On the basis of these assumptions, net losses in tree density due to unreplaced tree mortality occurred in more than 20 percent of the plots at each of 12 locations (*fig. 3*). Only at Pinnacles and Sierra did plots with net gains in density outnumber plots with net losses. The majority of plots at most locations show no net change in calculated blue oak stand densities.

We performed a similar calculation to compare the number of plots at each location that had gained or lost blue oak canopy cover. We assumed that saplings in the edge and open positions, but not those under canopy, represented a potential gain in canopy cover. The results of this comparison are very similar to those shown in *figure 3*. Almost all plots with increases in blue oak density also showed potential increases in blue oak canopy cover. In addition, for most locations the proportion of plots with decreased blue oak density was nearly equal to the proportion with decreased canopy cover. Only Pinnacles and Sierra had more plots with potential net gains in blue oak canopy than plots with net losses in blue oak canopy cover.
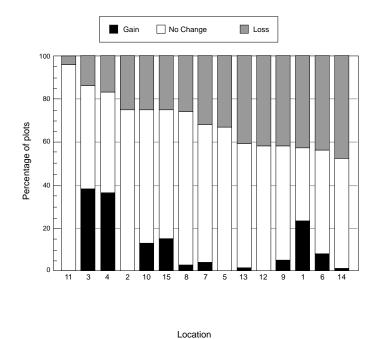
Stand Vegetation Characteristics

Blue oak trees occurred in at least 66 percent of the plots at each location. Stand purity and density (*table 4*) varied widely between locations. Based on the distribution of stump sprout trees, clearings, and other vegetation characteristics, it appeared that most if not all locations had been at least partially cleared or cut within the past 150 years. Other than blue oak, the most common tree canopy species in plots were *Q. agrifolia* Née, *Q. wislizenii* A.DC., *Q. lobata* Née, *Pinus sabiniana* Douglas, and *Aesculus californica* (Spach) Nutt. We observed that regeneration by other tree species varied widely by location and generally paralleled blue oak regeneration.

The majority of all sampled plots (56 percent) lacked any shrub cover, but the frequency of plots with shrubs varied widely between locations (*table 4*). Estimated shrub cover was less than 2.5 percent in over 49 percent of the plots that contained shrubs. The most commonly occurring shrubs within plots were *Arctostaphylos* spp., *Ceanothus cuneatus* var *cuneatus* (Hook.) Nutt., *Heteromeles arbutifolia* (Lindley) Roemer, *Rhamnus ilicifolia* Kellogg, and *Toxicodendron diversilobum* (Torrey & A. Gray) E. Greene. Regeneration of shrub species occurred mainly in the same locations with regeneration by canopy species.

In most locations, the plot herbaceous layer was dominated by non-native annual grasses. The frequency of plots containing native bunchgrasses, such as *Elymus glaucus* Buckley, *Festuca californica* Vasey, or *Nassella pulchra* (A. Hitchc.) Barkworth, ranged from 1 to 89 percent. Herbaceous cover was typically high and was rated as greater than 80 percent in 64 percent of all plots. However, only 4 percent of all plots had bunchgrass cover greater than 2.5 percent.

Discussion

There were large differences in sapling recruitment between the 15 locations, both in terms of total sapling counts (*figs. 1, 2*) and the proportions of plots with saplings (*tables 1, 3*). Moderate sapling populations were found at only four

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locations (Wantrup, Pinnacles, Sierra, and Jamestown). An equal number of locations had absolutely no saplings within the study area (*figs. 1, 2*). The study areas at Black Butte Lake, Pardee Reservoir, Hensley Lake, and the grazed portions of Hopland were notable for their virtually complete lack of regeneration by any woody species.

Our analysis of factors associated with sapling recruitment is presented in an accompanying paper (Swiecki and others, these proceedings). However, we could readily see that blue oak saplings, saplings of other canopy species, and understory shrubs were all sparse or absent from areas subjected to heavy browsing pressure from livestock. Most of the saplings we observed were in the S1 size class (*figs. 1, 2*), and chronic browsing was clearly limiting the height growth of most of these saplings. Griffin (1971) noted that browsing is a major constraint to oak sapling growth, and several other studies have found a preponderance of blue oak saplings shorter than the browse line (Borchert and others 1993, Harvey 1989, Muick and Bartolome 1987, White 1966).

Blue oak saplings stunted by browsing may be many decades old (Harvey 1989, McClaran 1986, Mensing 1992). Saplings in this small size class are susceptible to being severely damaged or killed by rodents, fires, or other agents that would not seriously affect larger saplings or trees. Chronic heavy browsing therefore contributes indirectly, if not directly, to mortality of S1 saplings.

There were relatively high proportions of dead saplings at a few locations (*tables 1, 3*), but actual sapling mortality rates cannot be determined from these counts. Dead saplings we observed almost certainly died within the past 10 to 15 years, as it is unlikely that they would persist longer than this. However, destructive agents such as fire or livestock would greatly shorten the period that dead saplings persist, leading to differences in counts of dead saplings between locations which are unrelated to sapling mortality.

We (*table 2*) and others (Muick and Bartolome 1987) have observed that blue oak saplings are more likely to occur in the open than under tree canopy. In contrast, small blue oak seedlings are most likely to be found under blue oak canopy (Muick and Bartolome 1987, Swiecki and others 1990, White 1966). We believe that this shift in distribution results when the seedling advance regeneration beneath the canopy is released through overstory mortality or removal (Swiecki 1990; Swiecki and others 1990, these proceedings). Because adequate populations of seedling advance regeneration are a necessary prerequisite for sapling recruitment in canopy gaps, destruction of small seedlings by livestock (Bernhardt and Swiecki, these proceedings) probably also contributes to the negative effects of grazing on sapling recruitment.

McCreary and others (1991) have demonstrated that blue oak stump sprouting success can vary widely between locations cut in a single year. Our data on stumps and stump sprouts provides further evidence that the success rate for sprout sapling establishment can vary widely between locations and between different years at a given location. From a management perspective, it would be very risky to rely exclusively on blue-oak stump sprouts to restock cut stands. Judging from the distribution of stump sprout trees, clearings, and other vegetation characteristics, we concluded that most if not all of the sampled stands had been at least partially cleared or cut within the past 150 years. However, sprout-origin blue oak trees were in the minority at all study locations (*table 3*).

Our estimates of natural mortality rates for blue oak trees are similar to those reported for other oaks in California (Brown and Davis 1991, Swiecki and others 1990). Our calculated mortality rates are based on subjective evaluations of whether trees had died within the past 30 years, and such estimates may either overestimate or underestimate the number of years since tree death. However, because some trees that died after 1962 were probably removed or destroyed

before our study, our calculated mortality rates probably underestimate actual mortality, in at least some locations.

By combining estimates of tree mortality and sapling recruitment, we can assess the adequacy of regeneration within each sampled stand. Our analysis indicates that sapling recruitment at 13 of 15 locations (87 percent) is inadequate to offset recent losses in blue oak density and canopy cover caused by natural mortality and tree cutting (*fig. 3*). Stand-level regeneration is probably even poorer than these figures indicate. Our analysis probably overestimates actual rates of regeneration because it includes the assumption that all live saplings will become trees. We believe that the stands we sampled represent a typical range of conditions in blue oak woodlands, and therefore our results indicate that poor regeneration rates may exist over large portions of the blue oak range. If such poor rates of regeneration persist over an extended period, the stand density and extent of blue oak woodlands are likely to decline over large portions of the existing range.

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