
Trunk and Root Sprouting on Residual Trees After Thinning a *Quercus chrysolepis* Stand

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ABSTRACT. Canyon live oak (*Quercus chrysolepis* Liebm.) showed sprouting patterns on root and trunk zones following forest thinning. Root sprouting was heaviest on north and east (downhill) sides of residual trees; bole sprouts were concentrated on the south and west (uphill). Root and bole sprouting appeared to be responding to different stimuli, or responding differently to the same kind of stimulus. Thinning affected sprout growth, but not sprout numbers. Sprouting responses were at the tree level rather than the thinning treatment level. Unexpected sprouting occurred in uncut control plots. Light, temperature, or mechanical activity may have affected sprouting on trees in the thinned plots. A better understanding of factors affecting sprout physiology in this species is required in order to fully explain sprouting responses following stand thinning. FOR. SCI. 37(1): 17-27.

ADDITIONAL KEY WORDS. Canyon live oak, *Quercus chrysolepis*, sprouting.

DECISIONS ON MANAGEMENT of California oak forests often rely on inadequate information about stand dynamics and treatment responses (Plumb and McDonald 1981). Thinning is a practice commonly used in many forest types to enhance stand productivity, improve wildlife habitat, or develop shaded fuelbreaks. One effect of thinning, in some species, is the production of stump sprouts. Within a thinned stand, trunk or root zone (root and rootcrown inclusive) sprouting may occur on residual trees. Sprouting could reflect the inherent capability of a species, the thinning activity, or the modified environment resulting from the thinning.

A sprouting habit is well documented for canyon live oak (*Quercus chrysolepis* Liebm.) stumps; yet, little is known about the factors that affect it. Sprouting in oaks is usually associated with injury caused by such activities as fire or logging. References to this habit are limited to rootcrown sprouting (McDonald and Littrell 1976, Talley and Griffen 1980, Minnich 1980, Plumb & Gomez 1983). Thornburgh (in press) reported that the size and vigor of parent trees directly affect the number of rootcrown sprouts and their early height growth. Conard (1987) found vigorous stump sprouting in both thinned and clearcut canyon live oak; stump sprouts sampled in thinned plots, however, were shorter and fewer than in clearcut plots.

This paper reports on the residual tree sprouting patterns associated with

thinning in a stand of canyon live oak. It explores the relationships between sprouting sites on the trees (e.g., aspect, root zone, upper or lower bole) and environmental triggers (e.g., temperature or light). We include, under the term "sprout," any shoot emerging from the root, the base of the tree, or the lowest 2 m of the bole.

METHODS

SITE DESCRIPTION

The study site is located on Skinner Ridge, elevation 1500 m, in the south central portion of the San Bernardino Mountains in southern California. Study plots are located on a north facing slope that has minor aspect variations. Slope topography varies from quite steep (approximately 35°) and convex to moderately sloped and concave. The soil type is considered to be in the Winthrop Family (sandy-skeletal, mixed mesic Entic Haploxerolls) based on the San Bernardino National Forest Soil Resource Inventory, Order Three. The site burned approximately 100 years ago.

The overstory is dominated by a closed canopy canyon live oak forest. The oak stand is composed of a mixture of single stemmed individuals and multiple stemmed clusters. Interior live oak (*Q. wislizenii* A. DC.) appears near the ridgetops and drainages. Occasional bigcone Douglas-fir (*Pseudotsuga macrocarpa* Vasey), white fir (*Abies concolor* [Gord. & Glend.] Lindl.), and California bay (*Umbellularia californica* [Hook & Arn.] Nutt.) are interspersed in this forest. Initial average stand density was 3100 trees/ha. Overstory tree height averaged 8.2 m and ranged from 3 m to 19.4 m. Diameter at breast height (dbh) averaged 16.5 cm and ranged from 3.9 cm to 37.3 cm.

The study area was divided into three blocks, each containing three plots. Within each block, each plot was randomly assigned one of three treatments: control, thin, and thin/burn. The thin/burn plot treatment had been thinned; burning will occur at a future date. Each plot measured 30 m by 40 m. Within each of the three control plots, 30 trees were randomly chosen to assess sprouting response. Similarly, in the thin and thin/burn plots, the 30 sample trees were chosen from individuals that were not marked for cutting.

TREATMENTS

The overstory oaks in the three thin plots and the three thin/burn plots were thinned from a stand basal area of 54 m²/ha to about 22.5 m²/ha. An attempt was made to distribute the thinning equitably across diameter size classes, and between single-stemmed trees and stems from multiple-stemmed clusters. Of the clusters that were thinned, generally only one or two stems per cluster were removed. The three control plots remained as uncut forest.

Thinning treatments were interrupted and prolonged by operational difficulties. Three plots were thinned during March through September 1984, and three were thinned during April 1985.

SAMPLING

Height, dbh, lower tree crown height, and number of cut and uncut stems per cluster were recorded for each of the 30 sample trees in each plot.

Four sprouting zones were identified on each sample tree (Figure 1). Zones A and B were used to determine sprouting on the bole of the tree. Zones C and D were used to determine basal sprouting. Zone C encompasses the root collar and area that develops as exposed, aboveground roots enlarge. Zone D comprises the underground area (to approximately 30 cm from the trunk) surrounding the base of the tree and from which root sprouts emerge.

Each of the four sprouting zones was divided into four quadrants (north, south, east, and west). The number, length, and diameter of all new (emerged since treatment) sprouts in each of the 20 quadrants were measured following completion of one growing season after the treatments. New plant material emerging from the bark or unhardened green stems of developed sprouts were considered to be new sprouts. Sprouts less than one millimeter in diameter were given a nominal 0.5 mm value.

ANALYSIS

Sprout numbers for the various sprouting zones were normalized, providing sprout density estimates. Sprouting areas were used as denominators in density expressions. The bole sprouting area was calculated by multiplying the two 1-m zones on each tree bole by circumference at dbh level (tree taper was minimal and not taken into account). The root zone area was assumed to be equivalent to a cylinder of one-third m height with circumference equal to that at dbh level. This area was divided equally between zones C and D. Sprout volume was estimated by assuming a neiloid frustum (e.g., Husch et al. 1982).

The interrupted thinning activity violated the blocking in the original experimental design. We converted the design to a symmetric balanced incomplete block (SBIB) design to capture the treatment pattern that emerged. This required

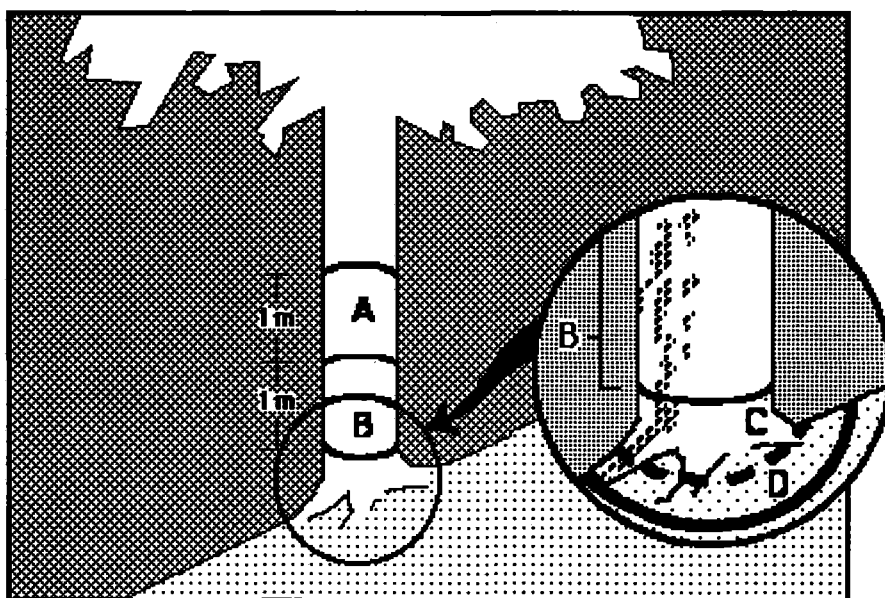


FIGURE 1. Bole and root sprouting zones.

randomly choosing one 1985 treatment for Block I, one 1984 treatment for Block III, and ignoring the control for Block II—resulting in the following design:

Treatment	Blocks		
	1	2	3
Control	X		X
Thin 1984		X	X
Thin 1985	X	X	

The SBIB design was used when a two-way analysis of variance was appropriate.

RESULTS AND DISCUSSION

PERCENTAGE OF TREES SPROUTING

Trees sprouted in all plots, including controls (Table 1). Timing of plot treatment had no clear effect on the number of trees that sprouted. Only one of the three control plots had the lowest percentages of trees that sprouted.

Evaluation of stem density and percent sprouting data summarized in Table 1 showed no consistent relationship between control and treatment plots within each of the different blocks. Analysis of variance using the SBIB approach and an arcsine transformation showed that block ($P = 0.73$) and treatment ($P = 0.79$) effects were both weak.

Differences in the proportions of trees sprouting between treated and control plots were judged not to be important. However, a chi-square test on a 2×2 contingency table (sprout/no sprout and control/thinned) did show a statistically

TABLE 1.

Tree density, percent of residual trees sprouting, and sprout density/tree by plot and zone. Bole = zone A + zone B; Root = zone C + zone D (Figure 2). Plot designations reflect blocks (numerical portion) and planned treatment (alphabetical portion).

Treatment and plot	Stems/ha			Sprout density/tree			
	Prethin Total	Postthin residual	Percent sprouting	Bole		Root	
				Mean	SD	Mean	SD
Thin 1984							
2A	2726	1325	63.33	11.58	22.72	73.37	108.28
3A	3875	1467	50.00	22.33	24.26	43.27	61.67
3B	2833	1233	73.33	30.45	51.06	148.95	168.68
Thin 1985							
1A	2158	1392	70.00	36.67	73.40	57.43	112.48
1B	2975	2133	73.33	22.91	32.25	16.32	47.11
2B	3625	1700	56.67	13.82	17.70	44.82	60.41
Control							
1C	3217	3217	60.00	44.33	67.26	58.00	113.88
2C	2625	2625	60.00	12.17	19.70	26.67	49.47
3C	3900	3900	40.00	14.33	17.57	2.00	6.93

significant ($P = 0.91$) difference in the proportions of trees that sprouted. However, the validity of this result is questionable because of the inconsistency in control plot responses. The need for consistency in forming judgment can be demonstrated by assuming that each tree has a 50/50 chance of sprouting, and considering the outcome of a set of binomial trials with $n = 30$ and a success probability of 0.50. The 95% confidence interval for the mean of this set lies between 0.32 and 0.68—nearly encompassing the range of sprouting proportions among our plots. Therefore, it would be difficult to distinguish the proportions of trees sprouting in this study from those that might occur as a result of pure chance.

More extensive testing is required before we can detect a definitive relationship between the level of thinning used in this study and the proportion of trees in a stand that sprout. A survey to determine background trunk and root zone sprouting levels in canyon live oak forests is needed to establish a more reliable basis for evaluating treatment results.

ZONATION OF SPROUTING

At the plot level, density of tree sprouts was generally greatest in the root portion (Table 1). Although lower, bole sprout density at the plot level was reasonably consistent and may represent the expected background level of sprouting for the bole portion.

Two distinct sprout centers were found to exist within a tree. At the plot level and at the overall study level, the root collar (zone C) tended to have the greatest mean sprout density, and the upper portion of the bole (zone A) had the second greatest. Sign tests indicated that, in general, more individual trees had a greater sprout density in bole zone A than in root zone C (Table 2). The difference between these two results is one of magnitude vs. frequency of occurrence. An analysis of variance on the difference in sprout density between these two zones did not indicate any block ($P = 0.11$) or treatment ($P = 0.27$) effects.

EFFECT OF TREATMENT TIMING

Sprout dimensions presented the only clear reflection of the staggered thinning treatment. Plot level means of average sprout volume per tree were higher in the plots cut early (Table 3). Plots thinned during March–September 1984 had the largest mean sprout volumes; plots thinned in April 1985 had moderate volumes; control plots had the smallest. Analysis of variance showed only a weak treatment effect ($P = 0.76$), because only some of the trees in the 1984 population had sprouts with large enough volumes to pull the mean higher than the 1985 and control populations (see Figure 2). However, pairwise comparison of the treatment groups, using the Wilcoxon two-sample rank sum test (which eliminates undue influence of a few extreme values), indicated a significant difference between the 1984 plots and all other plots (Table 4). This supports the idea that the 1984 population has a different structure than the others.

Differences in sprout length, diameter, and volume—effects attributable to the interrupted thinning schedule—were found in the root zone using the Wilcoxon two-sample rank sum test. These effects were weakly expressed in the bole

TABLE 2.

Study level test on differences in sprout density between bole zone A and root zone C (upper portion of table). Plot level statistics for root zone C and bole zone A density differences, $X_C - X_A = d$, for each tree that sprouted (lower portion of table).

Zone (plot level)	Sprout densities		Sign test of density (Zone C - Zone A) = d = 0			
	Mean	SD	(-) below	0 equal	(+) above	P above
A	11.17	19.94				
B	4.07	11.22				
C	23.66	50.63	90	17	57	0.998
D	6.09	19.16				
d						
Treatment and plot	Mean	SD				
Thin 1984						
2A	8.98	25.61	7	3	9	0.598
3A	5.63	37.76	9	3	3	0.019
3B	54.70	80.30	7	2	13	0.868
Thin 1985						
1A	13.20	69.80	10	2	9	0.324
1B	-4.43	37.46	18	1	3	0.000
2B	13.21	32.92	7	1	9	0.598
Control						
1C	10.17	31.92	12	1	5	0.025
2C	3.73	25.42	11	2	5	0.038
3C	-5.47	9.77	9	2	1	0.001

zone. Increased growth in proximity to the root zone may reflect a gravimorphic response (see Zimmermann and Brown 1971).

EFFECTS OF ASPECT

Distinct sprouting patterns emerged for the number of sprouts by quadrant for root and bole portions. Bole and root sprouts tended to concentrate on different sides of the trees. Bole sprouts were found most often on the south-facing quadrant (uphill), and secondarily on the west and east. Root sprouts occurred most frequently in the north (downhill), but also in the west- and east-facing quadrants (Table 5). An analysis of number of sprouting events (one or more sprouts in a quadrant) as a percent of total possible on trees that sprouted gave similar results (data not shown). Clearly, sprout numbers are strongly affected by location and position influences within the parent tree.

ZONATION OF SPROUTING VIGOR

Sprouting activity of individual trees concentrated in either the bole or root zone. Tendencies toward an "L" shape in scatter diagrams of the number of sprouts on the bole vs. the number of sprouts in the root area showed that if sprouting was

TABLE 3.

Mean of average sprout volume (cm^3) per tree for each plot by treatment. The first set of plots were thinned March–September 1984; the second set was thinned during April 1985.

Treatment and plot	Total		Bole		Root	
	Mean	SD	Mean	SD	Mean	SD
Thin 1984						
2A	0.153	0.238	0.058	0.055	0.192	0.274
3A	0.176	0.287	0.108	0.178	0.242	0.362
3B	0.149	0.178	0.137	0.188	0.172	0.167
Thin 1985						
1A	0.047	0.055	0.044	0.053	0.046	0.053
1B	0.029	0.027	0.027	0.027	0.039	0.021
2B	0.041	0.034	0.036	0.027	0.052	0.053
Control						
1C	0.030	0.023	0.025	0.012	0.043	0.032
2C	0.042	0.043	0.029	0.030	0.112	0.139
3C	0.036	0.035	0.039	0.035	0.004	—

strong in one of the areas, it was relatively weak in the other. Binomial tests on indicators of sprouting in both zones vs. sprouting in only one lent support to this observation (Table 6). Some notable trees in a few plots had an even distribution of sprouting vigor throughout and showed comparatively high sprouting activity. High sprouting activity in these trees may exist because the trees are more vigorous, as suggested by Thornburgh (in press), or it could result from a strong environmental sprouting trigger.

SPROUTING MECHANISMS

A consistent background level of sprouting was observed in these stands. Thinning may have triggered sprouting on residual trees; however, the intensity of thinning was not sufficient to greatly overcome background levels of sprouting. If thinning only improved sprout growing conditions, then sprout growth would differ while the number and location of sprouts would be independent of thinning treatment.

Concentration of bole sprouting on the south quadrant (uphill side) of trees suggests that insolation may be a critical sprouting trigger. This is similar to Wahlenberg's (1950) findings for yellow-poplar (*Liriodendron tulipifera* L.). Also, open-grown trees near our study plots tend to have heavier crowns on their south-facing side. Sprout abundance on south bole exposures could result from favorable light or temperature conditions—or both.

Insolation appears to be important in development of crown shoot and leaf material, but, insolation, as a sole sprouting trigger, does not explain the high concentration of root sprouts found on the north side of many trees. Bud dormancy is broken by exposure to cold for some species (Devlin 1975). Both thinning and natural soil movement could have exposed the north (downhill) root zones to cold temperatures which in turn may have broken dormancy in the root

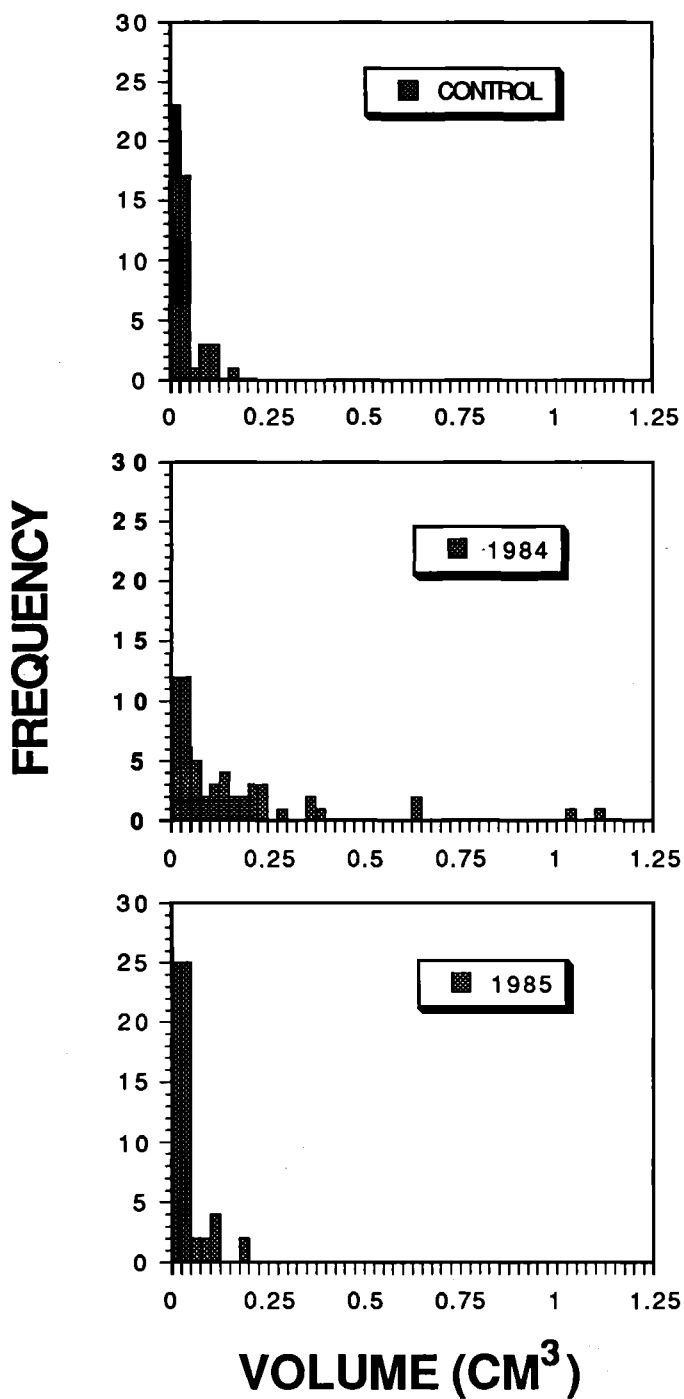


FIGURE 2. Frequency distributions of the sprout volumes per tree for thin plots (1984 and 1985) and control plots showing higher sprout volumes for the plots thinned in 1984.

TABLE 4.

Results of a pair-wise comparison of treatment groups. The three plots under each of the three treatments were pooled to form treatment groups. The test statistic, w , is from the Wilcoxon two sample rank sum test.

Comparison	$P(W < w)$	
Mean sprout volume:		
1984 vs. 1985	0.9999	
1984 vs. controls	0.9999	
1985 vs. controls	0.5977	
1984 vs. 1985	Bole	Root
number of sprouts	0.4710	0.9998
mean sprout density	0.3359	0.9997
mean sprout diameter	0.7571	0.9999
mean sprout length	0.8774	0.9999
mean sprout volume	0.9144	0.9999

TABLE 5.

Total numbers of sprouts by quadrant and zone. Rankings of the bole and root zone sprout numbers, in parentheses, illustrate that the highest concentrations of sprouts are in the north root and south bole portions (refer to unshaded numbers). Bole zone = zones A + B; root zone = zones C + D (Figure 2).

The Friedman's test showed that the number of sprouts within each zone differed significantly by aspect (bole: $P = 0.955$, root: $P = 0.999$). The

Wilcoxon signed-rank test was used for pairwise comparison of differences between aspects within each zone; the probabilities are shown at the bottom of the table.

Treatment and plot	Sprouts (ranks)							
	Bole				Root			
	N (downhill)	E	S (uphill)	W	N (downhill)	E	S (uphill)	W
Thin 1984								
2A	23 (4)	7 (1)	10 (2)	18 (3)	37 (3)	50 (4)	8 (2)	3 (1)
3A	3 (1)	20 (3)	58 (4)	16 (2)	11 (3)	6 (2)	0 (1)	22 (4)
3B	23 (1)	57 (3)	91 (4)	56 (2)	137 (4)	50 (3)	7 (1)	18 (2)
Thin 1985								
1A	13 (1)	17 (2)	104 (4)	47 (3)	20 (3)	28 (4)	2 (1)	11 (2)
1B	15 (1)	24 (2)	49 (4)	27 (3)	15 (4)	4 (3)	0 (1.5)	0 (1.5)
2B	6 (2)	5 (1)	28 (4)	22 (3)	35 (4)	11 (3)	3 (1)	4 (2)
Control								
1C	30 (1)	39 (2)	61 (4)	46 (3)	32 (4)	10 (3)	0 (1)	1 (2)
2C	19 (4)	17 (3)	11 (2)	5 (1)	11 (4)	5 (2)	4 (1)	8 (3)
3C	10 (4)	7 (1.5)	8 (3)	7 (1.5)	0 (2)	1 (4)	0 (2)	0 (2)
Wilcoxon P								
E	0.870				0.914			
S	0.975	0.990			0.994	0.996		
W	0.957	0.869	0.916		0.982	0.957	0.955	

TABLE 6.

Binomial tests on the proportion, pr , of trees that sprouted in either bole or root areas vs. trees that sprouted in both areas in each plot. (Null hypothesis: mean = 0.5; n = sample size).

Treatment and plot	pr	n	$P(P \leq p)$
Thin 1984			
2A	0.684	19	0.968
3A	0.533	15	0.696
3B	0.455	22	0.416
Thin 1985			
1A	0.857	21	0.999
1B	0.864	22	0.999
2B	0.647	17	0.928
Control			
1C	0.722	18	0.985
2C	0.944	18	0.999
3C	1.000	12	1.000

collar buds. If just the thinning activity caused new sprouting, then we would expect its effects to show up predominantly in the region suffering local mechanical abrasion and soil movement away from the tree.

Plausible explanations for high concentrations of sprouts in some zones leave large gaps in the sprouting picture for the tree as a whole. Whether sprouting in a given tree zone is a direct response to a local stimulus or an indirect response to a stimulus received in another part of the tree cannot be determined from this study. Some root zone sprouting might be attributed to the thinning activity, but localized root injury does not appear to be a major cause of sprouting.

RESPONSE LEVELS

Sprouting responses were clearly at the tree level among plots of uncut and thinned canyon live oak; the trees seemed to act independently of thinning treatment. The moderate level of thinning in this study improved sprout growth but did not show increased sprout initiation above background (control) rates. Factors necessary to induce sprouting either were not present in our treatments, or were insufficient to effect a noticeable difference among treatments.

Individual tree responses must be understood if stand level tests and evaluations are to be conducted. This understanding is mandatory before statistical hypothesis testing can be carried out. This study reports previously undocumented sprouting phenomena for canyon live oak trees: sprouting in untreated stands, and within-tree zonation of sprouting. Factors that trigger sprouting must be better understood before stand manipulation practices that either control or encourage residual tree sprouting can be prescribed.

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