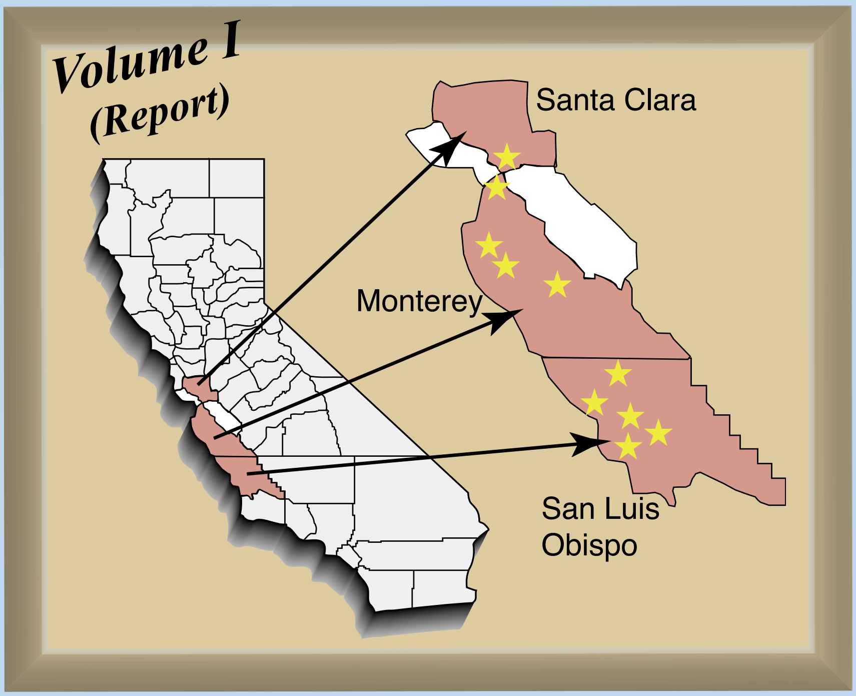
Long-Term Growth, Sudden Oak Death Assessment and Economic Viability of Coast Live Oak in Three California Counties

- Seventeen-Year Results -



by

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Technical Report No. 12
Urban Forest Ecosystems Institute
Natural Resources Management Department
California Polytechnic State University
San Luis Obispo, California

June 2004

ACKNOWLEDGMENTS

The authors would like to thank and acknowledge all who helped to see this project through to its completion. Special thanks to Dr. Tim Plumb, Michael De Lasaux, Jeff Reimer, and Wes Cruzen for their involvement, organizing, and valuable experience. We wish to thank all of the landowners for their patience, time, and for the use of their land upon which this project depends. Also we appreciate those who assisted in identifying grasses and forbs for the study (faculty in the Animal and Soil Science Departments at Cal Poly, and Dave Hacker of Caltrans). And lastly, thanks to the many other Cal Poly forestry students who have assisted with this project over the past 17 years.

The project was supported by the University of California Berkeley, California Department of Forestry and Fire Protection, the McIntire-Stennis Cooperative Forestry Research Program, USDA US Forest Service, and the California Agriculture Research Initiative program.

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VOLUME I (Report)

VOLUME II (Appendices)

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*Abstract: A long-term thinning study was established in ten stands of coast live oak (*Quercus agrifolia *Née) in the Central Coast of California in 1984. Information about diameter, basal area, and volume growth and yield has been obtained from unthinned control plots and from plots thinned to 50 and 100 square feet of basal area per acre. Plots were measured in 1984, 1989, 1996, and 2001. Both basal area and total volume growth percentages were significantly greater in the thinned plots compared to control plots. In 2001, Sudden Oak Death study plots were established around the growth plots. Although some trees exhibited suspicious symptoms, all laboratory tests were negative for the pathogen* Phytophthora ramorum *in the study plots.*

PREFACE

This report is the fourth major report that has been published on this study. The first report described the methodology and rationale for the thinning regime in significant detail:

Pillsbury, N. H., M. De Lasaux and T. R. Plumb. 1987. Coast live oak thinning study in the central coast of California. In: Plumb, T. R. and N. H. Pillsbury, technical coordinators. 1987. Proceedings of the symposium on Multiple-Use Management of California's Hardwood resources; November 12-14, 1986 San Luis Obispo, California. Gen. Tech. Rep. PSW-100. Berkeley, California: Pacific Southwest Forest and Range Experiment Station, Forest Service, US Department of Agriculture, pp. 92-97.

The second report, "Coast Live Oak Thinning Study in the Central Coast of California - Five-Year Results" (1989), provided the first information on coast live oak about diameter, basal area, and volume growth and yield from unthinned control plots and from plots thinned to 50 and 100 sf/ac measured. These results were also reported in the proceedings of the 1990 oak symposium:

Pillsbury, N. H. and J. P. Joseph. 1991. Coast live oak thinning study in the central coast of California — five-year results. In: Standiford, Richard B., tech. coordinator. 1991. Proceedings of the symposium on oak woodlands and hardwood rangeland management; October 31-November 2, 1990; Davis, California. Gen. Tech. Rept. PSW-126. Berkeley, CA: Pacific Southwest Research Station, Forest Service, U.S.D.A. 376 p.

The third report, "Coast Live Oak Thinning Study in The Central Coast of California-Twelve Year Results," extended the database and knowledge on coast live oak diameter, basal area, and volume growth and yield for the control, 50, and 100 sf/ac plots.

These results were also presented at the 2001 Symposium on Oak Woodlands in San Diego and reported in the proceedings of the symposium:

Pillsbury, Norman H., Lawrence E. Bonner, and Richard P. Thompson. 2001. Coast Live Oak Long-term Thinning Study—Twelve-Year Results. In: Standiford, Richard B.; McCreary, Douglas; Purcell, Kathryn L., technical coordinators. 2002. Proceedings of the fifth symposium on oak woodlands: oaks in California's changing landscape. 2001 October 22-25; San Diego, CA. Gen. Tech. Rep. PSW-GTR-184. Albany, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 846 p.

This, the fourth report, extends our knowledge about the effects of thinning in coast live oak stands to a seventeen-year period. In addition, with the incorporation of the sudden oak death plots, a baseline of information was established to study and monitor the spread of Sudden Oak Death.

INTRODUCTION AND BACKGROUND

California's oak woodlands continue to receive pressure for cutting, removal, and conversion. As a result, the coast live oak ecosystem is continuing to decline in extent and health. These woodlands are an under-utilized resource that could provide a continuous source of wood fiber for energy and wood products, given appropriate management.

Coast live oak (*Quercus agrifolia* Née) was selected for this study because of its extensive range in California, covering about 750,000 acres from San Diego to Mendocino County. Previous studies (Pillsbury 1978; Pillsbury and De Lasaux 1985) involving inventory of coast live oak stands showed that they are typically dense, ranging from 100 to over 700 trees per acre (averages for these studies varies from 300-350) and basal area ranges from about 75 to 250 square feet per acre (averages for these studies are 150-160). Tree spacing ranged from about 7 to 20 feet (average of 12-13) while average tree diameter for the stands varied from about 5 to 17 inches (averages of 10-11). Coast live oak stands are largely between 40 and 110 years of age, although stands have been measured as young as 28 years and as old as 131 years. Typically they average 60-80 years in age. Site index values varied from a low of 32 feet to a high of 84 feet at 50 years.

There are no coast live oak studies that show the effects of thinning on the growth of the residual stand. Thinnings are normally conducted to stimulate the growth of remaining trees and to increase the total yield of useful fiber from the stand. The basic objectives of thinning are: a) to redistribute the growth potential of the stand into fewer but larger trees, and, b) to utilize all the merchantable material produced by the stand prior to harvest (Smith 1962).

The age that the final harvest would occur (rotation) for coast live oak was examined in a preliminary site, growth and yield study on the central coast (Pillsbury and De Lasaux 1985). Based on the growth rate and stand condition, a biological rotation of a stand could be as early as 50 years, although a harvest at age 75 or 80 would be feasible especially for stands on lower quality sites.

Currently, little is known about site productivity, regeneration, tree growth, and the potential effects of harvesting on oak woodlands. Little information is available on different management practices and their effects. Through the establishment of permanent plots, growth can be documented over time. These data will prove valuable to foresters and landowners who wish to maximize fiber production in existing stands or want to compare the potential for different management strategies.

The primary long-term goal of this study is to establish a series of permanent plots to develop long-term diameter, basal area, and volume growth and yield information for thinned and unthinned stands of coast live oak in Monterey, San Luis Obispo, and Santa Clara counties.

An increase in the rate of expansion of urban areas into the wildland interface has resulted in unique management problems for local government. One of the goals of this study, from an economics perspective, is to develop management strategies for both reducing costs associated with fire suppression while protecting oak woodland ecosystem values.

A new aspect of the study in 2001 was the detection for *Phytophthora ramorum* into the study as the causal agent of Sudden Oak Death. The primary reason is to monitor potential spread through coast live oak stands and to aid in reporting any newly infected counties or species. This disease has the potential to greatly affect mortality rates as well as overall health and existence of coast live oak stands throughout the central coast of California. Because this study evaluates the health, vigor, and growth rates of coast live oak stands, it was essential that the effects of this disease be incorporated into the study.

Other objectives of this study include the following:

a) Evaluate the changes in understory vegetation following thinning;
b) Evaluate the regeneration of coast live oak (stump sprouts and seedlings) following thinning; and
c) Evaluate disturbance of soils during the thinning process and the effects of such disturbance.

Many of the stands measured in previous studies are near rotation age, therefore it is important to know if they could benefit from thinning. This study may help to determine if thinning of older stands will yield increased fiber while allowing for immediate income from the removed trees.

PLOT ESTABLISHMENT AND INITIAL INVENTORY

Plot Selection

Initially, ten sites were selected for this study and were distributed as follows: Monterey County - four sites, San Luis Obispo County - five sites, and Santa Clara County - one site (Figure 1). Three plots were established at each site consisting of one control plot and two plots that were thinned to 50 and 100 square feet per acre respectively. Plots were established in stands approximately 40 to 85 years old.

Each plot is one-fifth acre in size and surrounded by a two-fifths acre buffer zone for a total area of three-fifths acre. Plots were established by compass and tape, and metal rebar was used to monument plot corners. The incorporation of sudden oak death into the study necessitated a larger plot size for this component. The entire three-fifths acre plot was used for the sudden oak death survey (Figure 2).

Thinning Prescription

The strategy used for cutting was a combination improvement cut and low thinning. Trees on thinned plots were removed if they:

a) were not coast live oak,
b) were damaged or defective,
c) were less than 6 inches dbh,
d) were one stem of a forked tree,
e) were of suppressed or intermediate crown class, or
f) were of poor vigor (see Pillsbury and others 1987).

In most cases, further basal area reduction was needed to obtain either 50 or 100 sf/ac basal area for the plot. Trees designated as "cut trees" during initial field measurements were automatically removed from the stand. These were mostly small diameter trees (less than 6 inches) of poor vigor and were either in the suppressed or intermediate crown class. Additional trees were removed if they:

g) were obviously from a previous stand,
h) were not sawlog quality or size, or
i) were too closely spaced to an adjacent tree.

Table 1, section F, shows which plots are treatment (thinned) and which plots are control.

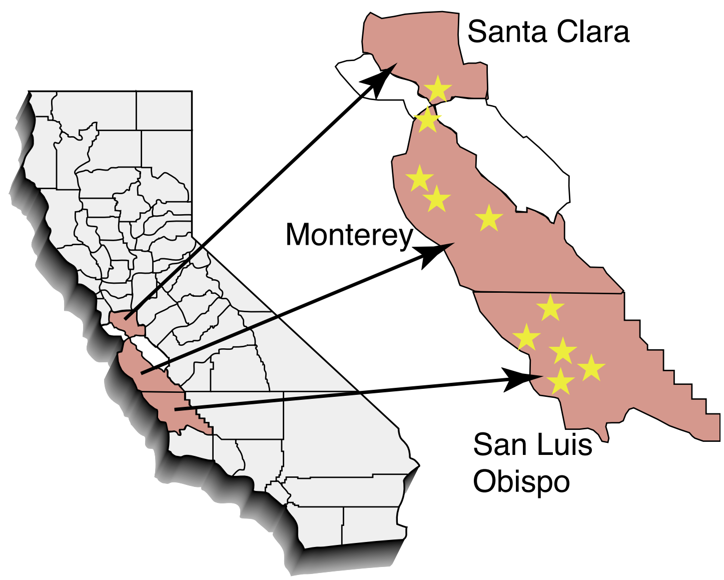

Figure 1. Map of coast live oak thinning plots.

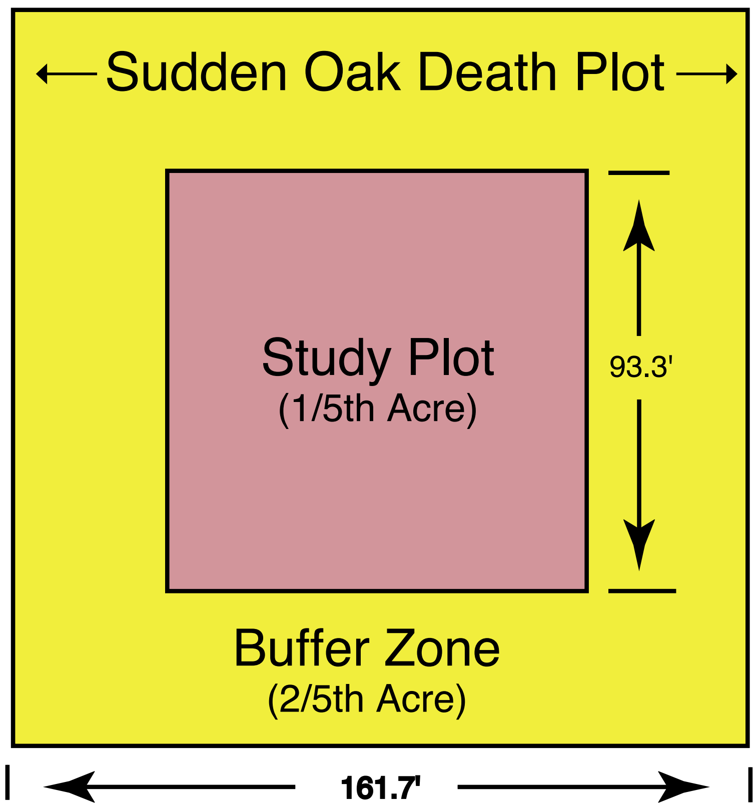

Figure 2. A typical thinning plot, sudden oak death plot, and buffer zone design and layout.

Only for plot 3-2 was it found that thinning to 100 square feet basal area per acre would not remove enough basal area to meet the stand management objectives. The residual basal area for this plot was reduced to 75 square feet per acre.

Data Collection

Using a computer application called Future Basic II, a series of computer programs were written to develop 90 stand, basal area, and stock tables plus a number of other tables needed to summarize the data. From this array of information, we were able to chart the course of stand growth and change in the coast live oak thinning plots. Standard mensuration formulae were used to calculate basal area, number of trees per acre, and tree volume.

Specific information collected and a description of the measurement and units are provided in Table 1.

Development of Stand, Basal Area, and Stock Tables

Tree volume equations (Table 2) used in the study were of the following form:

$$\text{Volume (cu.ft.)} = b_0(\text{Dbh})^{b_1} (\text{Height})^{b_2} (\text{Sawlog Indicator})^{b_3}$$

where: Dbh is diameter at breast-height in inches,

Height is total height in feet,

Volume is in cubic feet based on one of the three utilization standards discussed in Table 2, and,

Sawlog Indicator is a code of "1" or "10." A value of "10" means the tree meets the sawlog criteria discussed in Table 2, and a value of "1" means that it does not meet sawlog standards. If the tree is not of sawlog quality and size, the last term can be dropped from the equation, and b_0, b_1, b_2, are regression coefficients.

Basic mensurational data were compiled for each plot before and after thinning, and after each subsequent inventory, and extrapolated to a per-acre stand basis. A stand table consisting of the number of trees of a given species per diameter class per acre was developed. Trees were grouped into 2-inch diameter classes (e.g., the 8-inch class includes trees 7.0 through 8.9 inches). Basal area tables (square feet per acre by species and diameter class) and stock tables (cubic foot volume of trees of a given species per diameter class per acre) were also developed.

Tree volumes for hardwoods were computed according to three utilization standards: total volume, wood volume, and sawlog volume. Total volume is the total outside bark volume including the stump. Wood volume is inside bark volume from stump height (1 foot) to a 4-inch top (inside bark) for all stems. Sawlog volume is the inside bark volume found in trees having an 11-inch or greater dbh and having straight, sound segments 8 feet or greater in length, from stump height to a 9-inch top diameter inside bark (Pillsbury and Kirkley 1984). Only total volumes were computed for non-hardwood species.

REMEASUREMENT OF STANDS (2001)

Analysis

Coast live oak plot data were analyzed for change in stand density and volume growth. It should be noted that thinning studies have traditionally been evaluated solely on change in

Table 1. Data collected at thinning plots. Variables shown in **bold** print were measured during all inventories after 1984; variables shown non-bold were measured during the initial 1984 inventory.

	VARIABLE	UNITS	DESCRIPTION	
A. Overstory			Common Name	Scientific Name
	Species	Code	1 = Valley oak	*Quercus lobata*
			2 = Blue oak	*Quercus douglasii*
			3 = Tanoak	*Lithocarpus densiflorus*
			4 = Laurel	*Umbellularia californica*
			5 = Big leaf maple	*Acer macrophyllum*
			6 = Knobcone pine	*Pinus attenuatta*
			7 = Foothill pine	*Pinus sabiniana*
			8 = Madrone	*Arbutus menziesii*
			9 = Coast live oak	*Quercus agrifolia*
	Dbh	inches	Diameter at breast height, taken at location of nail, to the nearest 0.1 inches.	
	Total Height	feet	Total height to top of terminal leader, to nearest 1 foot.	
	Merchantability Indicator	Code	"1" if first 8' log is not merchantable; "10" if dbh is 11" or greater and first 8' log is straight and sound (Pillsbury, N. and M. Kirkley. 1984).	
	Tree Vigor	Code	Relative tree vigor 3 = low, 2 = medium and 1 = high	
	Azimuth	degrees	Clockwise angle from north to tree, taken from the center of plot to the nearest 1 degree.	
	Horizontal Distance	feet	Horizontal distance from plot center to tree center to the nearest 1 foot.	
	Crown Class	Code	1 = Dominant, 2 = Codominant, 3 = Intermediate, 4 = Suppressed.	
B. Understory Shrubs				
	Ground Cover	percent	a) Grasses and forbs, b) Litter, and c) bare ground or rock	
			Common Name	Scientific Name
	Woody Shrub Cover	Code & percent	1 = Red Berry	*Rhamnus crocea*
			2 = Coffeeberry	*R. californica*
			3 = Buckeye	*Aesculus californica*
			4 = Mtn Mahogony	*Cercocarpus betuloides*
			5 = Toyon	*Heteromeles arbutifolia*
			6 = Elderberry	*Sambucus glauca*
			7 = Poison oak	*Rhus diversiloba*
			8 = Coyote Bush	*Bacharis pilularis*
			9 = Monkey Flower	*Diplacus aurantiacus*
			10 = Vetch	*Vicia*
			11 = Ribes	*Ribes* spp
			12 = Honeysuckle	*Lonicera* spp

--- *continued* ---

Table 1. Data collected at thinning plots (continued).

VARIABLE	UNITS	DESCRIPTION	
Woody Shrub Cover	Code & percent	Common Name	Scientific Name
		13 = Blackberry	*Rubus vitifolius*
		14 = Creambush	*Holodiscus discolor*
		15 = Snowberry	*Symphoricarpus mollis*
		16 = Lupine	*Lupinus albiphrons*
		17 = Black sage	*Salvia mellifera*
		18 = Deerweed	*Lotus scoparius*
Sprouts & Stumps			
Clumps	code	For browsed sprouts in mound form, "A" if clump is < 2' dia., "B" when dia. is 2-3', and "C" when > 3' dia.	
Sprout	yes/no	When one sprout in a mound attains a height of at least 3" above the mound surface and is unbrowsed.	
Sprout Height	inches	For each sprouted stump that was not in a "mound" form, both tallest sprout and an average height.	
Sprout Number	count	Each major stem was counted up to a maximum of 15.	
Stump Diameter	inches	Measured with a Cruisers Stick to the nearest inch.	
Stump Angle	degrees	Estimated to the nearest 5 degrees from the level position.	
Stump Height	inches	Measured from the uphill side to the uppermost part of the stump with a Cruiser Stick.	
Forage			
Species	name	The scientific symbols used are from the "National List of Plant Names", USDA, Soil Conservation Service, SCS-TP-159, January 1982.	
Extent	percent	Occularly estimated to the closest 5 percent at the site.	
Weight	lbs/ac	2' x 2' samples (4 sf) were taken, oven dried, weighed, and then total forage weight was calculated, by plot.	
Other			
Ground	percent	Percent of bare soil to the closest 5 percent.	
Rock	percent	Percent of exposed rock to the closest 5 percent.	
Litter	percent	Percent cover of plant residue (i.e., oak leaves) to the closest 5 percent.	
C. Soil Surface Condition			
Erosion	percent	a) rills b) gullies, c) slides or slumps	
D. Stand and Site Information			
Slope	percent	Measured with clinometer to nearest 1 unit.	
Aspect	bearing	Measured with hand compass to nearest 1 degree.	

-- continued --

Table 1. Data collected at thinning plots (continued).

D. Stand and Site Information (continued)

Elevation	feet	Determined from USGS topographic map, to nearest 20'.
Soil Type	name	Determined from SCS Soil Survey.
Stand Crown	percent	Closure was estimated by sight to nearest 5 percent.
Site Age	years	An average of 1 to 4 of the tallest trees in the plot, measured at breast height, nearest 1 year.
Site Index	feet & rating	Determined from site index rating curves for coast live oak (Pillsbury and DeLasaux, 1985). Nearest 1 foot. Ratings: High, Medium, Low.

E. Plot Identification Information

ID METHOD	DESCRIPTION
Quad Name	Taken from USGS Topographic 7.5' maps.
Aerial Photo Numbers	Sequence numbers taken from CDF aerial photos located at CDF Headquarters, Monterey, CA. Flight Line & Photo numbers.
Planimetric Stem Map	A stem map was developed for each plot to show the location of each tree and its relative size.
Plot Access Information	A detailed plot location narrative, sketch and ownership information for each site.

F. Plot Descriptions and Location

Site Number	Treatment	Location/USFS Quad./County
1-1	100	Cuesta Grade/Lopez Mountain/San Luis Obispo
1-2	Control	" " " " "
1-3	50	" " " " "
2-1	50	Elkhorn Slough Estuarine/Prunedale/Monterey
2-2	Control	" " " " "
2-3	100	" " " " "
3-1	50	Arian Ramage/Adelaida/San Luis Obispo
3-2	100	" " " "
3-3	Control	" " " "
4-1	100	Santa Lucia Conservancy/Mt. Carmel/Monterey
4-2	50	" " " "
4-3	Control	" " " "
5-1	50	Chualar/Gonzales/Monterey
5-2	Control	" " "
5-3	100	" " "
6-1	50	Castro Valley Ranch/Watsonville/San Benito
6-2	Control	" " " " "
6-3	100	" " " " "
7-1	100	Rana Creek Ranch/Rana Creek/Monterey
7-2	50	" " " "
7-3	Control	" " " "
8-1	100	Presenti Winery/Templeton/San Luis Obispo
8-2	50	" " " " "
8-3	Control	" " " " "
9-1	100	Prefumo Cyn/Morro Bay South/San Luis Obispo
9-2	50	" " " " "
9-3	Control	" " " " "
10-1	50	Lopez Lake/Lopez/San Luis Obispo
10-2	Control	" " " "
10-3	100	" " " "

-- continued --

Table 1. Data collected at thinning plots (continued).

G. Sudden oak death measurements.

The following variables were measured for the two-fifths acre plot that surrounded each one-fifth acre growth and yield plot.

<u>Variables measured</u>: tree number, dbh, quadrant where tree is located, damage and disease, and signs or symptoms of sudden oak death.

Table 2. Tree volume equations used in central coast thinning study.

Coefficient Species	Utilization Standard	Intercept Coefficient a	Diameter Coefficient b	Height Coefficient c	Indicator d
Coast Live Oak	TV	0.0065261029	2.31958	0.62528	—
	WV	0.0024574847	2.53284	0.60764	—
	SV	0.0006540144	2.24437	0.81358	0.43381
Blue Oak	TV	0.0125103008	2.33089	0.46100	—
	WV	0.0042324071	2.53987	0.50591	—
Valley Oak	TV	0.0042870077	2.33631	0.74872	—
	WV	0.0009684363	2.39565	0.98878	—
	SV	0.0001880044	1.87346	1.62443	—
Tanoak	TV	0.0058870024	1.94165	0.86562	—
	WV	0.0005774970	2.19576	1.14078	—
Madrone	TV	0.0067322665	1.96628	0.83458	—
	WV	0.0025616425	1.99295	1.01532	—
Laurel	TV	0.0057821322	1.94553	0.88389	—
	WV	0.0016380753	2.05910	1.05293	—
Big Leaf Maple	TV	0.0101786350	2.22462	0.57561	—
	WV	0.0034214162	2.35347	0.69586	—
Pinus spp.	TV	0.001319897	2.01859	1.03906	—

Notes:

TV = Total volume: includes all stem and branch wood plus stump and bark; excluding foliage.

WV = Wood volume: computed from stump height (1') to a 4" top outside bark; excluding bark and foliage.

SV = Sawlog volume: computed for trees 11 inches dbh and larger; volume computed from stump height to a 9" outside bark top for straight sections 8' long; excluding bark and foliage.

basal area per acre of the stand. The traditional approach is relatively simple and therefore easily understood. A disadvantage is that it does not fully evaluate changes in stand volume, which is the desired product. The approach used in this study is to look at all five variables to improve our interpretation of the stands' response to thinning: number of trees, basal area, and volume (total, wood, and sawlog).

Maintenance and Changes in Plot Condition

In general, plots were in good condition. However, some changes were made to several sites including updating the directions and distances to the sites, and correcting errors.

Due to the tree growth in the last 5 years, many tags were either embedded in the bark or close to being embedded. Any tags that were embedded into the bark layer were dug out and both the nail and tag removed, if possible, and replaced with a new tag of the same number. If for any reason the number was changed, the new number was noted. In some cases, the tag and nail were embedded too far into the tree to allow removal without harming the tree. In these cases, the tree was given a new tag with the original number. All tags that were close to being embedded were pulled further away from the tree to allow for growth.

Changes in Analysis

In the 1984 and 1989 measurements and analysis, the total volume for all coast live oak trees was computed using a local volume equation (without heights) while height was included for all other species. This was done in an attempt to gain some precision of the volume estimate. After further consideration, it was decided that including heights for all species for the 1996 data would provide a more consistent approach. This change required that data from the previous two periods be recomputed using heights in the tree volume equation in order to make a valid comparison with 1996 data. For this reason, it should be noted that any comparison between the 1996 report and previous reports will be different, and it is not recommended that previous information be used.

To allow for comparison of the 1996 data set and previous data sets, we reanalyzed all previous data, and this reanalysis was included in the 1996 report. This includes new stand and stock tables that used tree heights for all species. This change only applied to total volume, not wood or sawlog volume. This approach has been used in all subsequent measurement periods.

Information pertaining to specific sites or plots is presented below. This information is from observations during summer 2001.

Site 1, Cuesta Grade - During the first 12 years of the study, this site experienced two intensive burns, one in the summer of 1985 and the other in the summer of 1994. In both fires, more trees were lost in the control plots than in the thinned plots. The effects of these fires are still very much apparent in 2001. The control plot actually has fewer living trees than either thinned plot and all countable ingrowth in these plots has been of non-coast live oak species. A full discussion of mortality and ingrowth is presented in the section titled "Seventeen-Year Results of Thinning Treatments."

Site 4, Santa Lucia Conservancy (formerly San Carlos Ranch) - Urban development at this site is beginning to encroach on the study plots and may cause them to be unusable for any valid measurements or comparisons in the future. Plot 4-3 (control plot) now has a paved road running diagonally from the southwest corner to the northeast corner. As of the 2001 inventory, only four trees were removed for the road. All four trees were fairly small in size, ranging from 3.8 to 10 inches dbh. However, effects on understory, forage, water runoff, soil erosion, and percolation as well as loss of possible ingrowth must also be considered with such a large area of the plot now paved. In addition, further development and an increase in human impact on the area may occur again.

Plot 4-2 (50 sf/ac) has development taking place just east of the plot. The development has not yet directly affected the original plot; however, the SOD plot was established 34.2 feet west of the growth and yield plot center in order to avoid being affected. Further use of this site will be evaluated during the next inventory.

Site 5, Chualar - A change in ownership occurred between 1989 and 1996 at this site. This caused difficulty in tracking down the landowner and gaining access during both the 1996 and 2001 inventories.

The jeep trail used to gain access to this site is a very steep and narrow dirt road, therefore it is highly recommended that a four-wheel-drive vehicle be used. In addition, there is now a locked gate approximately 1500 feet up the jeep trail. There is no place to turn around at or before the gate, and if a lock combination is not acquired it is recommended that access be gained by parking at the base of the trail and hiking in.

The understory of both plot 5-2 and 5-3 appears to have been disturbed by humans (*i.e.*, grazing and/or grading) as they have very little understory vegetation. The understory is primarily made up of a thick layer of coast live oak litter.

Site 6, Castro Valley Ranch - A change in ownership between the 1989 and 1996 inventories resulted in the denial of access to this site in 1996. Therefore, in an attempt to keep the site in the study, the data for this site was extrapolated over seven years from the 1989 database for the 1996 report.

After another change of ownership, access was once again granted in 2001. Unfortunately, the previous management allowed the entire site to be extensively harvested. In order to avoid skewing the growth data for the entire study, this site was removed from the database. This included removing all data for site 6 starting with the initial inventory in 1984 in order to make comparison among years valid. For this reason the database in this report consists of only nine sites and should not be compared to previous reports. All data for all measurement periods were reanalyzed in this report in order to make proper comparisons among years without site 6. This reanalysis is included in this report.

Further, it should be noted that site 6 was one of the most productive sites in the study. Removing this site had a noticeable effect on total volume, basal area, and mortality averages.

Although this site will no longer be used for the growth and yield study, it will be retained for the new sudden oak death section of the study.

<u>Seventeen-Year Results of Thinning Treatments</u>

The effects of the thinning treatments after seventeen years is discussed below for the following stand characteristics: number of stems, basal area, total volume, wood volume, and sawlog volume. The data are presented in Tables 3 and 4 on the following pages. Three

TABLE 3. Summary of pre-treatment and successive inventories, and annual growth per acre.

STAND TABLE (Stems/acre)

Plot Number	PT	1984 Inv.	1989 Inv.	1996 Inv.	2001 Inv.	2001 Ingrowth	Mortality/Ingrowth per acre/yr (M/I) 1984-89	1984-96	1984-01
CONTROL PLOTS									
1-2	400	400	185	75	70	5	-43.0	-27.1	-19.7
2-2	385	385	380	380	365	0	-1.0	-0.4	-1.2
3-3	610	610	580	420	375	0	-6.0	-15.8	-13.8
4-3	330	330	330	305	295	10	0.0	-2.1	-2.6
5-2	75	75	75	80	80	0	0.0	0.4	0.3
6-2	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
7-3	280	280	245	225	220	0	-7.0	-4.6	-3.5
8-3	270	270	255	235	225	0	-3.0	-2.9	-2.6
9-3	150	150	135	135	135	0	-3.0	-1.3	-0.9
10-2	210	210	150	130	125	0	-12.0	-6.7	-5.0
Ave =	**301.1**	**301.1**	**259.4**	**220.6**	**210.0**	**1.7**	**-8.3**	**-6.7**	**-5.5**
PLOTS THINNED TO 100 SQ. FT./ACRE									
1-1	480	200	195	160	185	50	-1.0	-3.3	-3.8
2-3	355	95	95	95	135	50	0.0	0.0	-0.6
3-2	725	325	310	295	300	0	-3.0	-2.5	-1.5
4-1	310	95	95	95	95	0	0.0	0.0	0.0
5-3	215	60	60	60	60	0	0.0	0.0	0.0
6-3	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
7-1	300	175	175	170	165	0	0.0	-0.4	-0.6
8-1	290	110	105	105	100	0	-1.0	-0.4	-0.6
9-1	90	45	45	45	45	0	0.0	0.0	0.0
10-3	505	100	100	95	95	0	0.0	-0.4	-0.3
Ave =	**363.3**	**133.9**	**131.1**	**124.4**	**131.1**	**11.1**	**-0.6**	**-0.8**	**-0.8**
PLOTS THINNED TO 50 SQ. FT./ACRE									
1-3	555	110	105	90	80	0	-1.0	-1.7	-1.8
2-1	400	70	70	65	280	220	0.0	-0.4	-0.6
3-1	835	215	210	200	205	0	-1.0	-1.3	-0.6
4-2	145	30	30	30	30	0	0.0	0.0	0.0
5-1	110	30	30	30	30	0	0.0	0.0	0.0
6-1	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
7-2	235	55	55	55	55	0	0.0	0.0	0.0
8-2	225	45	45	45	45	0	0.0	0.0	0.0
9-2	105	40	40	40	40	0	0.0	0.0	0.0
10-1	290	60	60	60	60	0	0.0	0.0	0.0
Ave =	**322.2**	**72.8**	**71.7**	**68.3**	**91.7**	**24.4**	**-0.2**	**-0.4**	**-0.3**

BASAL AREA TABLE (Sq ft/acre)

Plot Number	PT	1984 Inv.	1989 Inv.	1996 Inv.	2001 Inv.	Growth per acre/yr 1984-89	1984-96	1984-01
CONTROL PLOTS								
1-2	155	155	131	76	70	-4.8	-6.6	-5.0
2-2	253	253	268	281	285	3.0	2.3	1.9
3-3	138	138	148	130	134	2.0	-0.7	-0.2
4-3	255	255	266	265	273	2.2	0.8	1.1
5-2	176	176	185	196	206	1.8	1.7	1.8
6-2	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
7-3	105	105	111	116	123	1.2	0.9	1.1
8-3	180	180	185	195	207	1.0	1.3	1.6
9-3	191	191	177	181	184	-2.8	-0.8	-0.4
10-2	153	153	145	133	146	-1.6	-1.7	-0.4
Ave =	**178.4**	**178.4**	**179.6**	**174.8**	**180.9**	**0.2**	**-0.3**	**0.1**
PLOTS THINNED TO 100 SQ. FT./ACRE								
1-1	145	97	107	106	102	2.0	0.8	0.3
2-3	242	109	124	135	133	3.0	2.2	1.4
3-2	106	82	101	113	115	3.8	2.6	1.9
4-1	184	99	108	120	129	1.8	1.8	1.8
5-3	168	106	114	125	132	1.6	1.6	1.5
6-3	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
7-1	123	97	102	106	111	1.0	0.8	0.8
8-1	157	102	107	114	123	1.0	1.0	1.2
9-1	166	98	104	111	118	1.2	1.1	1.2
10-3	203	102	110	112	123	1.6	0.8	1.2
Ave =	**166.0**	**99.1**	**108.6**	**115.8**	**120.7**	**1.9**	**1.4**	**1.3**
PLOTS THINNED TO 50 SQ. FT./ACRE								
1-3	156	60	73	76	77	2.6	1.3	1.0
2-1	177	52	66	70	98	2.8	1.5	2.7
3-1	132	67	87	109	129	4.0	3.5	3.6
4-2	170	63	69	75	80	1.2	1.0	1.0
5-1	144	52	56	67	77	0.8	1.3	1.5
6-1	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
7-2	106	54	57	63	67	0.6	0.8	0.8
8-2	135	56	62	67	74	1.2	0.9	1.1
9-2	152	78	85	90	104	1.4	1.0	1.5
10-1	125	60	63	74	77	0.6	1.2	1.0
Ave =	**144.1**	**60.2**	**68.7**	**76.8**	**87.0**	**1.7**	**1.4**	**1.6**

TOTAL VOLUME (Cu ft/acre)

Plot Number	PT	1984 Inv.	1989 Inv.	1996 Inv.	2001 Inv.	Growth per acre/yr 1984-89	1984-96	1984-01
CONTROL PLOTS								
1-2	3337	3337	3068	2089	1743	-53.8	-104.0	-93.8
2-2	5534	5534	7172	7566	7684	327.6	169.3	126.5
3-3	3438	3438	3687	3352	3675	49.8	-7.2	13.9
4-3	9055	9055	10656	10803	11146	320.2	145.7	123.0
5-2	6799	6799	7898	8415	9080	219.8	134.7	134.2
6-2	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
7-3	2195	2195	2694	2851	3144	99.8	54.7	55.8
8-3	5574	5574	6237	6719	7407	132.6	95.4	107.8
9-3	5581	5581	6130	6281	6341	109.8	58.3	44.7
10-2	4057	4057	4093	3756	4205	7.2	-25.1	8.7
Ave =	**5063.3**	**5063.3**	**5737.2**	**5759.1**	**6047.2**	**134.8**	**58.0**	**57.9**
PLOTS THINNED TO 100 SQ. FT./ACRE								
1-1	3293	2391	2475	2498	2362	16.8	8.9	-1.7
2-3	5962	2941	4108	4274	4397	233.4	111.1	85.6
3-2	2396	2014	2662	3155	3190	129.6	95.1	69.2
4-1	5430	3238	4088	4603	5000	170.0	113.8	103.6
5-3	5009	3687	4387	4838	5256	140.0	95.9	92.3
6-3	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
7-1	2459	2099	2431	2592	2768	66.4	41.1	39.4
8-1	4836	3437	3588	3889	4438	30.2	37.7	58.9
9-1	5472	3334	4022	4336	4709	137.6	83.5	80.9
10-3	5247	3024	3390	3497	4003	73.2	39.4	57.6
Ave =	**4456.0**	**2907.2**	**3461.2**	**3742.4**	**4013.7**	**110.8**	**69.6**	**65.1**
PLOTS THINNED TO 50 SQ. FT./ACRE								
1-3	3219	1357	1583	1656	2003	45.2	24.9	38.0
2-1	3780	1232	1824	1979	2766	118.4	62.3	90.2
3-1	3058	1875	2582	3355	4215	141.4	123.3	137.6
4-2	6606	2550	3046	3369	3834	99.2	68.3	75.5
5-1	4682	1830	1991	2409	2911	32.2	48.3	63.6
6-1	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
7-2	2322	1408	1552	1730	1911	28.8	26.8	29.6
8-2	4385	2130	2566	2806	3247	87.2	56.3	65.7
9-2	4419	2450	2953	3156	3760	100.6	58.8	77.1
10-1	3027	1619	1805	2134	2369	37.2	42.9	44.1
Ave =	**3944.2**	**1827.9**	**2211.3**	**2510.4**	**3001.8**	**76.7**	**56.9**	**69.1**

Notes:
PT = Pre-Treatment inventory, Spring 1984.
1984 Inv. = First Inventory; residual stand immediately following the 1984 thinning.
1989 Inv. = Second inventory; measured after five years growth, Summer 1989.
1996 Inv. = Third inventory; measured after twelve years growth, Spring/Summer 1996.
2001 Inv. = Fourth inventory; measured after seventeen years growth, Summer 2001.
1984-1989 M/I = Mortality (minus values) or Ingrowth (plus values) after five years growth, Summer 1989 (stems per acre).
1984-1996 M/I = Mortality (minus values) or Ingrowth (plus values) after twelve years growth, Spring/Summer 1996 (stems per acre).
1984-2001 M/I = Mortality (minus values) or Ingrowth (plus values) after seventeen years growth, Summer 2001 (stems per acre).
1984-89 = Annual growth over the first five year period (1984-1989).
1984-96 = Annual growth over an twelve year period (1984-1996).
1984-01 = Annual growth over an seventeen year period (1984-2001).
n/a = Trees in plot cut between inventories.

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TABLE 3 (continued). Summary of pre-treatment and successive inventories, and annual growth per acre.

Plot Number	WOOD VOLUME (Cu ft/acre) PT	1984 Inv.	1989 Inv.	1996 Inv.	2001 Inv.	Growth per acre/yr 1984-89	1984-96	1984-01	SAWLOG VOLUME (Cu ft/acre) PT	1984 Inv.	1989 Inv.	1996 Inv.	2001 Inv.	Growth per acre/yr 1984-89	1984-96	1984-01
CONTROL PLOTS																
1-2	1981	1981	1880	1303	1100	-20.2	-56.5	-51.8	183	183	251	270	244	13.6	7.3	3.6
2-2	3362	3362	4364	4627	4740	200.4	105.4	81.1	0	0	0	0	0	0.0	0.0	0.0
3-3	1895	1895	2057	1888	2096	32.4	-0.6	11.8	49	49	49	49	49	0.0	0.0	0.0
4-3	6052	6052	7175	7329	7607	224.6	106.4	91.5	3225	3225	3955	4069	4272	146.0	70.3	61.6
5-2	4685	4685	5453	5839	6350	153.6	96.2	97.9	1463	1463	1746	1870	2060	56.6	33.9	35.1
6-2	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
7-3	1282	1282	1590	1695	1881	61.6	34.4	35.2	0	0	0	0	0	0.0	0.0	0.0
8-3	3489	3489	3908	4265	4745	83.8	64.7	73.9	1354	1354	1510	1703	1914	31.2	29.1	32.9
9-3	3597	3597	3953	4059	4110	71.2	38.5	30.2	605	605	815	827	759	42.0	18.5	9.1
10-2	2555	2555	2607	2419	2743	10.4	-11.3	11.1	107	107	120	41	50	2.6	-5.5	-3.4
Ave =	**3210.9**	**3210.9**	**3665.2**	**3713.8**	**3930.2**	**90.9**	**41.9**	**42.3**	**776.2**	**776.2**	**938.4**	**981.0**	**1038.7**	**32.4**	**17.1**	**15.4**
PLOTS THINNED TO 100 SQ. FT./ACRE																
1-1	1952	1382	1452	1494	1435	14.0	9.3	3.1	42	42	58	71	77	3.2	2.4	2.1
2-3	3661	1858	2616	2751	2853	151.6	74.4	58.5	0	0	0	0	0	0.0	0.0	0.0
3-2	1274	1092	1480	1779	1798	77.6	57.3	41.5	47	47	65	71	71	3.6	2.0	1.4
4-1	3379	2038	2586	2938	3212	109.6	75.0	69.1	973	922	1209	1316	1389	57.4	32.8	27.5
5-3	3239	2477	2952	3278	3576	95.0	66.8	64.6	328	328	406	434	452	15.6	8.8	7.3
6-3	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
7-1	1464	1266	1471	1577	1695	41.0	25.9	25.2	0	0	0	0	0	0.0	0.0	0.0
8-1	2895	2114	2232	2440	2822	23.6	27.2	41.6	1151	1088	1165	1269	1526	15.4	15.1	25.8
9-1	3665	2249	2717	2947	3226	93.6	58.2	57.5	920	402	492	519	499	18.0	9.8	5.7
10-3	3147	1872	2112	2193	2537	48.0	26.8	39.1	328	208	245	276	310	7.4	5.7	6.0
Ave =	**2741.8**	**1816.4**	**2179.8**	**2377.4**	**2572.7**	**72.7**	**46.8**	**44.5**	**421.0**	**337.4**	**404.4**	**439.6**	**480.4**	**13.4**	**8.5**	**8.4**
PLOTS THINNED TO 50 SQ. FT./ACRE																
1-3	1843	792	952	1015	1245	32.0	18.6	26.6	55	55	84	105	109	5.8	4.2	3.2
2-1	2230	744	1124	1239	1732	76.0	41.3	58.1	0	0	0	0	0	0.0	0.0	0.0
3-1	1698	1108	1531	2020	2563	84.6	76.0	85.6	206	206	220	232	253	2.8	2.2	2.8
4-2	4332	1687	2032	2268	2600	69.0	48.4	53.7	2579	885	1057	1167	1341	34.4	23.5	26.8
5-1	3144	1250	1367	1662	2043	23.4	34.3	46.6	155	0	0	0	0	0.0	0.0	0.0
6-1	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
7-2	1390	879	973	1093	1215	18.8	17.8	19.8	69	69	59	72	85	-2.0	0.3	0.9
8-2	2692	1371	1661	1825	2130	58.0	37.8	44.6	1144	966	1184	1277	1482	43.6	25.9	30.4
9-2	2914	1641	1989	2136	2582	69.6	41.3	55.4	93	93	111	123	131	3.6	2.5	2.2
10-1	1823	1005	1125	1351	1509	24.0	28.8	29.6	0	0	0	0	0	0.0	0.0	0.0
Ave =	**2451.8**	**1164.1**	**1417.1**	**1623.2**	**1957.7**	**50.6**	**38.3**	**46.7**	**477.9**	**252.7**	**301.7**	**330.7**	**377.9**	**9.8**	**6.5**	**7.4**

Notes:
- PT = Pre-Treatment inventory, Spring 1984.
- 1984 Inv. = First Inventory; residual stand immediately following the 1984 thinning.
- 1989 Inv. = Second inventory; measured after five years growth, Summer 1989.
- 1996 Inv. = Third inventory; measured after twelve years growth, Spring/Summer 1996.
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- 1984-1989 M/I = Mortality (minus values) or Ingrowth (plus values) after five years growth, Summer 1989
- 1984-1996 M/I = Mortality (minus values) or Ingrowth (plus values) after twelve years growth, Spring/Summer 1996.
- 1984-2001 M/I = Mortality (minus values) or Ingrowth (plus values) after seventeen years growth, Summer 2001.
- 1984-89 = Annual growth over the first five year period (1984-1989).
- 1984-96 = Annual growth over an twelve year period (1984-1996).
- 1984-01 = Annual growth over an seventeen year period (1984-2001).
- n/a = Trees in plot cut between inventories.

TABLE 4. Mortality, growth in number of stems, basal area and total volume in the central coast of California.

CONTROL PLOTS

	STAND TABLE (all trees)			BASAL AREA TABLE (all trees)			BASAL AREA TABLE (Coast Live Oak only)			TOTAL VOLUME (all trees)			TOTAL VOLUME (Coast Live Oak only)		
Plot Number	Five-year Mortality (trees/ac)	Twelve-year Mortality (trees/ac)	Seventeen-year Mortality (trees/ac)	(Stand) Average Growth ('84-'89) (sq. ft./ac/yr)	(Stand) Average Growth ('84-'96) (sq. ft./ac/yr)	(Stand) Average Growth ('84-'01) (sq. ft./ac/yr)	Avg ('84-'89) Growth per Tree (sf/ac/yr)	Avg ('84-'96) Growth per Tree (sf/ac/yr)	Avg ('84-'01) Growth per Tree (sf/ac/yr)	(Stand) Average Growth ('84-'89) (cu. ft./ac/yr)	(Stand) Average Growth ('84-'96) (cu. ft./ac/yr)	(Stand) Average Growth ('84-'01) (cu. ft./ac/yr)	Avg ('84-'89) Growth per Tree (cf/ac/yr)	Avg ('84-'96) Growth per Tree (cf/ac/yr)	Avg ('84-'01) Growth per Tree (cf/ac/yr)
1-2	-215.0	-325	-335	-4.8	-6.6	-5.0	0.04	0.03	0.04	-53.8	-104.0	-93.8	0.34	0.29	0.14
2-2	-5.0	-5	-20	3.0	2.3	1.9	0.04	0.03	0.03	327.6	169.3	126.5	0.86	0.44	0.38
3-3	-30.0	-190	-235	2.0	-0.7	-0.2	0.03	0.03	0.03	49.8	-7.2	13.9	0.14	0.15	0.20
4-3	0.0	-25	-45	2.2	0.8	1.1	0.04	0.03	0.04	320.2	145.7	123.0	0.96	0.56	0.51
5-2	0.0	5	5	1.8	1.7	1.8	0.11	0.10	0.11	219.8	134.7	134.2	2.89	1.76	1.75
6-2	n/a	n/a	n/a	n/a	n/a	n/a	0.06	0.06	n/a	n/a	n/a	n/a	0.48	0.36	n/a
7-3	-35.0	-55	-60	1.2	0.9	1.1	0.03	0.03	0.03	99.8	54.7	55.8	0.42	0.27	0.28
8-3	-15.0	-35	-45	1.0	1.3	1.6	0.03	0.04	0.05	132.6	95.4	107.8	0.53	0.45	0.53
9-3	-15.0	-15	-15	-2.8	-0.8	-0.4	0.06	0.04	0.04	109.8	58.3	44.7	1.72	0.81	0.60
10-2	-60.0	-80	-85	-1.6	-1.7	-0.4	0.06	0.05	0.07	7.2	-25.1	8.7	0.45	0.31	0.44
Ave. =	-41.7	-60.6	-92.8	0.2	-0.3	0.1	0.05	0.04	0.05	134.8	58.0	57.9	0.88	0.54	0.54

PLOTS THINNED TO 100 SQ. FT./ACRE

Plot Number	Five-year Mortality (trees/ac)	Twelve-year Mortality (trees/ac)	Seventeen-year Mortality (trees/ac)	(Stand) Average Growth ('84-'89) (sq. ft./ac/yr)	(Stand) Average Growth ('84-'96) (sq. ft./ac/yr)	(Stand) Average Growth ('84-'01) (sq. ft./ac/yr)	Avg ('84-'89) Growth per Tree (sf/ac/yr)	Avg ('84-'96) Growth per Tree (sf/ac/yr)	Avg ('84-'01) Growth per Tree (sf/ac/yr)	(Stand) Average Growth ('84-'89) (cu. ft./ac/yr)	(Stand) Average Growth ('84-'96) (cu. ft./ac/yr)	Average Growth ('84-'01) (cu. ft./ac/yr)	Avg ('84-'89) Growth per Tree (cf/ac/yr)	Avg ('84-'96) Growth per Tree (cf/ac/yr)	Avg ('84-'01) Growth per Tree (cf/ac/yr)
1-1	-5.0	-40	-65	2.0	0.8	0.3	0.06	0.06	0.06	16.8	8.9	-1.7	0.10	0.18	0.19
2-3	0.0	0	-10	3.0	2.2	1.4	0.16	0.12	0.11	233.4	111.1	85.6	2.43	1.15	1.12
3-2	-15.0	-30	-25	3.8	2.6	1.9	0.07	0.05	0.04	129.6	95.1	69.2	0.45	0.36	0.25
4-1	0.0	0	0	1.8	1.8	1.8	0.10	0.09	0.09	170.0	113.8	103.6	1.77	1.18	1.08
5-3	0.0	0	0	1.6	1.6	1.5	0.12	0.13	0.12	140.0	95.9	92.3	2.30	1.58	1.52
6-3	n/a	n/a	n/a	n/a	n/a	n/a	0.09	0.10	n/a	n/a	n/a	n/a	0.78	0.64	n/a
7-1	0.0	-5	-10	1.0	0.8	0.8	0.03	0.03	0.03	66.4	41.1	39.4	0.38	0.27	0.26
8-1	-5.0	-5	-10	1.0	1.0	1.2	0.08	0.06	0.08	30.2	37.7	58.9	0.48	0.44	0.69
9-1	0.0	0	0	1.2	1.1	1.2	0.13	0.12	0.13	137.6	83.5	80.9	3.02	1.83	1.77
10-3	0.0	-5	-5	1.6	0.8	1.2	0.08	0.06	0.08	73.2	39.4	57.6	0.72	0.48	0.65
Ave. =	-2.8	-9.4	-13.9	1.9	1.4	1.3	0.09	0.08	0.08	110.8	69.6	65.1	1.24	0.81	0.84

PLOTS THINNED TO 50 SQ. FT./ACRE

Plot Number	Five-year Mortality (trees/ac)	Twelve-year Mortality (trees/ac)	Seventeen-year Mortality (trees/ac)	(Stand) Average Growth ('84-'89) (sq. ft./ac/yr)	(Stand) Average Growth ('84-'96) (sq. ft./ac/yr)	(Stand) Average Growth ('84-'01) (sq. ft./ac/yr)	Avg ('84-'89) Growth per Tree (sf/ac/yr)	Avg ('84-'96) Growth per Tree (sf/ac/yr)	Avg ('84-'01) Growth per Tree (sf/ac/yr)	(Stand) Average Growth ('84-'89) (cu. ft./ac/yr)	(Stand) Average Growth ('84-'96) (cu. ft./ac/yr)	Average Growth ('84-'01) (cu. ft./ac/yr)	Avg ('84-'89) Growth per Tree (cf/ac/yr)	Avg ('84-'96) Growth per Tree (cf/ac/yr)	Avg ('84-'01) Growth per Tree (cf/ac/yr)
1-3	-5.0	-20	-30	2.6	1.3	1.0	0.14	0.11	0.11	45.2	24.9	38.0	0.47	0.44	0.65
2-1	0.0	-5	-10	2.8	1.5	2.7	0.20	0.14	0.18	118.4	62.3	90.2	1.67	1.09	1.44
3-1	-5.0	-15	-10	4.0	3.5	3.6	0.10	0.09	0.09	141.4	123.3	137.6	0.67	0.62	0.66
4-2	0.0	0	0	1.2	1.0	1.0	0.19	0.17	0.18	99.2	68.3	75.5	3.26	2.24	2.48
5-1	0.0	0	0	0.8	1.3	1.5	0.15	0.21	0.25	32.2	48.3	63.6	1.06	1.59	2.09
6-1	n/a	n/a	n/a	n/a	n/a	n/a	0.07	0.08	n/a	n/a	n/a	n/a	0.55	0.47	n/a
7-2	0.0	0	0	0.6	0.8	0.8	0.06	0.07	0.07	28.8	26.8	29.6	0.52	0.48	0.53
8-2	0.0	0	0	1.2	0.9	1.1	0.12	0.10	0.12	87.2	56.3	65.7	1.91	1.24	1.44
9-2	0.0	0	0	1.4	1.0	1.5	0.17	0.12	0.19	100.6	58.8	77.1	2.48	1.45	1.90
10-1	0.0	0	0	0.6	1.2	1.0	0.06	0.09	0.09	37.2	42.9	44.1	0.61	0.71	0.73
Ave. =	-1.1	-4.4	-5.6	1.7	1.4	1.6	0.13	0.12	0.14	76.7	56.9	69.1	1.32	1.03	1.32

n/a = Trees in plot cut between inventories.

--- continued ---

TABLE 4 (continued). Growth in wood volume, and sawlog volume for coast live oak in the central coast of California.

CONTROL PLOTS

Plot Number	WOOD VOLUME (all trees) (Stand) Average Growth ('84-'89) (cu. ft./ac/yr)	WOOD VOLUME (all trees) (Stand) Average Growth ('84-'96) (cu. ft./ac/yr)	WOOD VOLUME (all trees) (Stand) Average Growth ('84-'01) (cu. ft./ac/yr)	WOOD VOLUME (Coast Live Oak only) Avg ('84-'89) Growth per Tree (cf/ac/yr)	WOOD VOLUME (Coast Live Oak only) Avg ('84-'96) Growth per Tree (cf/ac/yr)	WOOD VOLUME (Coast Live Oak only) Avg ('84-'01) Growth per Tree (cf/ac/yr)	SAWLOG VOLUME (all trees) (Stand) Average Growth ('84-'89) (cu. ft./ac/yr)	SAWLOG VOLUME (all trees) (Stand) Average Growth ('84-'96) (cu. ft./ac/yr)	SAWLOG VOLUME (all trees) (Stand) Average Growth ('84-'01) (cu. ft./ac/yr)	SAWLOG VOLUME (Coast Live Oak only) Avg ('84-'89) Growth per Tree (cf/ac/yr)	SAWLOG VOLUME (Coast Live Oak only) Avg ('84-'96) Growth per Tree (cf/ac/yr)	SAWLOG VOLUME (Coast Live Oak only) Avg ('84-'01) Growth per Tree (cf/ac/yr)
1-2	-20.2	-56.5	-51.8	0.23	0.19	0.11	13.6	7.3	3.6	1.36	0.72	0.36
2-2	200.4	105.4	81.1	0.53	0.28	0.25	0.0	0.0	0.0			
3-3	32.4	-0.6	11.8	0.09	0.09	0.12	0.0	0.0	0.0	-0.03	-0.01	-0.01
4-3	224.6	106.4	91.5	0.68	0.40	0.37	146.0	70.3	61.6	1.62	0.90	0.77
5-2	153.6	96.2	97.9	2.05	1.27	1.30	56.6	33.9	35.1	1.88	1.13	1.17
6-2	n/a	n/a	n/a	0.31	0.24	n/a	n/a	n/a	n/a	1.13	0.79	n/a
7-3	61.6	34.4	35.2	0.26	0.17	0.17	0.0	0.0	0.0			
8-3	83.8	64.7	73.9	0.34	0.30	0.36	31.2	29.1	32.9	0.57	0.53	0.60
9-3	71.2	38.5	30.2	1.14	0.54	0.41	42.0	18.5	9.1	1.68	0.74	0.36
10-2	10.4	-11.3	11.1	0.30	0.22	0.31	2.6	-5.5	-3.4	0.26	0.07	0.16
Ave. =	90.9	41.9	42.3	0.59	0.37	0.38	32.4	17.1	15.4	1.06	0.61	0.49

PLOTS THINNED TO 100 SQ. FT./ACRE

Plot Number	WOOD VOLUME (all trees) (Stand) Average Growth ('84-'89) (cu. ft./ac/yr)	WOOD VOLUME (all trees) (Stand) Average Growth ('84-'96) (cu. ft./ac/yr)	WOOD VOLUME (all trees) (Stand) Average Growth ('84-'01) (cu. ft./ac/yr)	WOOD VOLUME (Coast Live Oak only) Avg ('84-'89) Growth per Tree (cf/ac/yr)	WOOD VOLUME (Coast Live Oak only) Avg ('84-'96) Growth per Tree (cf/ac/yr)	WOOD VOLUME (Coast Live Oak only) Avg ('84-'01) Growth per Tree (cf/ac/yr)	SAWLOG VOLUME (all trees) (Stand) Average Growth ('84-'89) (cu. ft./ac/yr)	SAWLOG VOLUME (all trees) (Stand) Average Growth ('84-'96) (cu. ft./ac/yr)	SAWLOG VOLUME (all trees) (Stand) Average Growth ('84-'01) (cu. ft./ac/yr)	SAWLOG VOLUME (Coast Live Oak only) Avg ('84-'89) Growth per Tree (cf/ac/yr)	SAWLOG VOLUME (Coast Live Oak only) Avg ('84-'96) Growth per Tree (cf/ac/yr)	SAWLOG VOLUME (Coast Live Oak only) Avg ('84-'01) Growth per Tree (cf/ac/yr)
1-1	14.0	9.3	3.1	0.08	0.13	0.14	3.2	2.4	2.1	0.64	0.49	0.42
2-3	151.6	74.4	58.5	1.60	0.78	0.76	0.0	0.0	0.0			
3-2	77.6	57.3	41.5	0.27	0.22	0.15	3.6	2.0	1.4	0.75	0.41	0.29
4-1	109.6	75.0	69.1	1.15	0.79	0.73	57.4	32.8	27.5	1.64	0.94	0.79
5-3	95.0	66.8	64.6	1.58	1.11	1.08	15.6	8.8	7.3	3.10	1.76	1.46
6-3	n/a	n/a	n/a	0.48	0.41	n/a	n/a	n/a	n/a			n/a
7-1	41.0	25.9	25.2	0.23	0.17	0.17	0.0	0.0	0.0			
8-1	23.6	27.2	41.6	0.34	0.31	0.48	15.4	15.1	25.8	0.28	0.27	0.47
9-1	93.6	58.2	57.5	2.08	1.29	1.28	18.0	9.8	5.7	1.21	0.65	0.38
10-3	48.0	26.8	39.1	0.48	0.32	0.44	7.4	5.7	6.0	0.50	0.38	0.40
Ave. =	72.7	46.8	44.5	0.83	0.55	0.58	13.4	8.5	8.4	1.16	0.70	0.60

PLOTS THINNED TO 50 SQ. FT./ACRE

Plot Number	WOOD VOLUME (all trees) (Stand) Average Growth ('84-'89) (cu. ft./ac/yr)	WOOD VOLUME (all trees) (Stand) Average Growth ('84-'96) (cu. ft./ac/yr)	WOOD VOLUME (all trees) (Stand) Average Growth ('84-'01) (cu. ft./ac/yr)	WOOD VOLUME (Coast Live Oak only) Avg ('84-'89) Growth per Tree (cf/ac/yr)	WOOD VOLUME (Coast Live Oak only) Avg ('84-'96) Growth per Tree (cf/ac/yr)	WOOD VOLUME (Coast Live Oak only) Avg ('84-'01) Growth per Tree (cf/ac/yr)	SAWLOG VOLUME (all trees) (Stand) Average Growth ('84-'89) (cu. ft./ac/yr)	SAWLOG VOLUME (all trees) (Stand) Average Growth ('84-'96) (cu. ft./ac/yr)	SAWLOG VOLUME (all trees) (Stand) Average Growth ('84-'01) (cu. ft./ac/yr)	SAWLOG VOLUME (Coast Live Oak only) Avg ('84-'89) Growth per Tree (cf/ac/yr)	SAWLOG VOLUME (Coast Live Oak only) Avg ('84-'96) Growth per Tree (cf/ac/yr)	SAWLOG VOLUME (Coast Live Oak only) Avg ('84-'01) Growth per Tree (cf/ac/yr)
1-3	32.0	18.6	26.6	0.33	0.30	0.44	5.8	4.2	3.2	0.57	0.41	0.3
2-1	76.0	41.3	58.1	1.09	0.72	0.97	0.0	0.0	0.0			
3-1	84.6	76.0	85.6	0.40	0.38	0.41	2.8	2.2	2.8	0.38	0.41	0.5
4-2	69.0	48.4	53.7	2.30	1.61	1.79	34.4	23.5	26.8	1.72	1.17	1.3
5-1	23.4	34.3	46.6	0.78	1.14	1.55	0.0	0.0	0.0			
6-1	n/a	n/a	n/a	0.33	0.29	n/a	n/a	n/a	n/a			n/a
7-2	18.8	17.8	19.8	0.34	0.32	0.36	-2.0	0.3	0.9	-0.41	0.04	0.2
8-2	58.0	37.8	44.6	1.29	0.84	0.99	43.6	25.9	30.4	1.09	0.65	0.8
9-2	69.6	41.3	55.4	1.74	1.03	1.38	3.6	2.5	2.2	0.72	0.50	0.5
10-1	24.0	28.8	29.6	0.40	0.48	0.49	0.0	0.0	0.0			
Ave. =	50.6	38.3	46.7	0.9	0.7	0.9	9.8	6.5	7.4	0.7	0.5	0.6

n/a = Trees in plot cut between inventories.

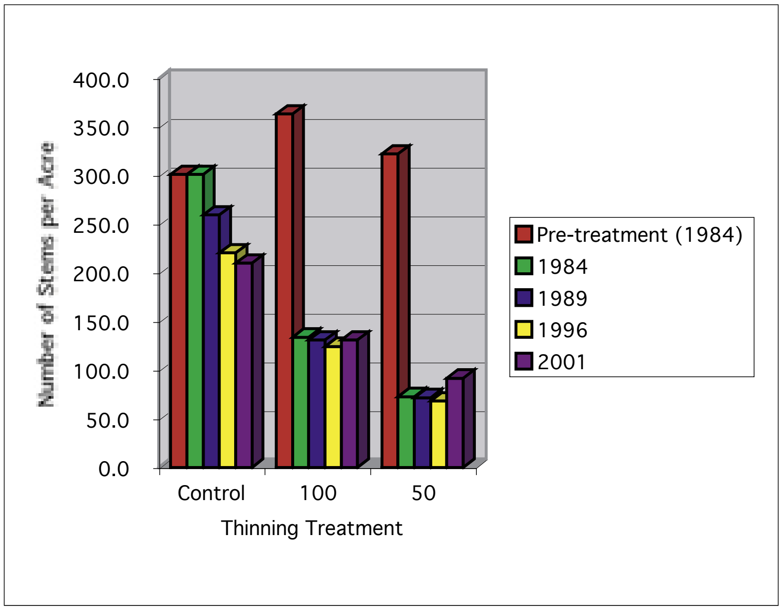


Figure 3. Number of stems per acre by treatment type.

treatments were used: control plots (no thinning), plots thinned to 100 sf/ac, and plots thinned to 50 sf/ac.

At each site, a control plot was established to provide a benchmark for comparing the response of the thinned plot.

<u>Number of Stems per Acre</u>

<u>Ingrowth</u>: Any change in the number of stems per acre that would occur would be due to either ingrowth or mortality. Trees are counted as ingrowth and included in the sample when they are at least one inch in diameter at breast height (4.5 ft.). The first ingrowth was observed in the 1996 inventory with 6 trees being counted as ingrowth throughout the 10 sites. Most changes in the number of stems per acre during the first 12 years were basically a result of mortality.

However, as predicted in the 1996 report, ingrowth began to show a greater presence in the 2001 inventory (Figure 3). The largest amount of ingrowth was seen in Site 2. The 50 sf/ac plot had approximately 220 trees per acre of coast live oak ingrowth. The 100 sf/ac plot had 50 trees per acre of coast live oak ingrowth, and the control plot had zero ingrowth. Overall, three sites had ingrowth, including Sites 1, 2, and 4. Within these sites, ingrowth occurred in one 50 sf/ac plot, two 100 sf/ac plots, and two control plots.

The 50 sf/ac plots averaged 24.4 trees per acre ingrowth while the 100 sf/ac plots averaged 11.1 trees per acre and the control plots only 1.7 trees per acre. However, all of the ingrowth in the 50 sf/ac plots took place at Site 2, which, surprisingly, had one of the lowest site indexes of all sites. Site index is the height growth in feet attained in 50 years. It is shown in rank order in the chart below.

Site No.	Site Index
7	32.4
2	36.1
9	39.5
10	42.3
6	47.4
1	52.4
8	53.0
5	57.6
4	70.2
3	84.5

The presence of ingrowth is just beginning to have an effect on the study; it is still too early to make any broad conclusions as to how it is affected by the different thinning treatments.

Species is another factor that needs to be considered in order to analyze the new ingrowth data. Only coast live oak ingrowth occurred at Sites 2 and 4. Site 1, which was dramatically affected by fire, had no countable

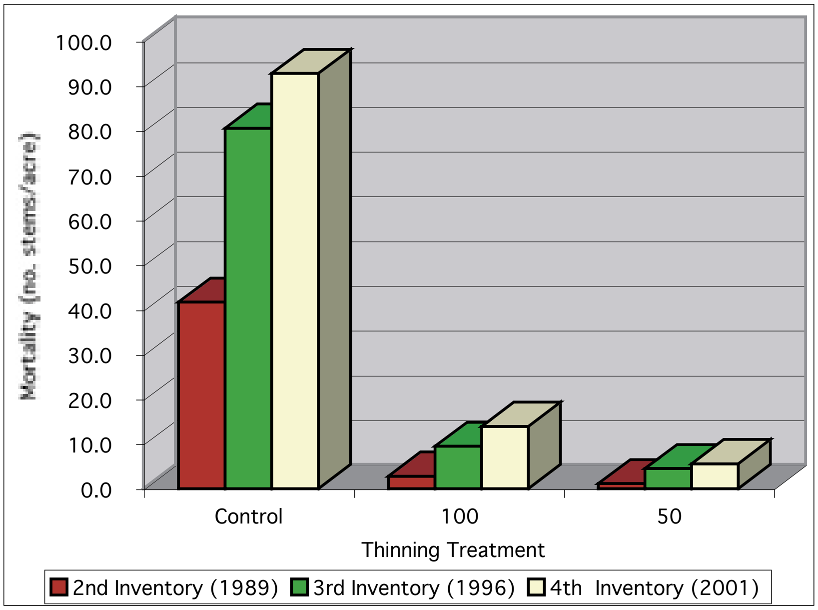


Figure 4. Mortality for control and treatment plots.

coast live oak ingrowth. The 100 sf/ac basal area plot had 10 madrone trees accounting for 50 trees per acre ingrowth, and the control plot had one knobcone pine accounting for 5 trees per acre ingrowth. The dramatic fire events and their effect on the soil, crown cover, site temperature, and overall stand health may have initiated a slight shift in species composition throughout the site. However, it should also be noted that there is a strong presence of coast live oak regeneration at the clump and sprout stage in Site 1's treatment plots. Many of the sprouts fell just under the one-inch-at-breast-height requirement for countable ingrowth and are expected to reach the ingrowth stage within the next couple of years. Because regeneration is still in the early stages in all 10 sites, it is anticipated that the next inventory will give a much clearer picture of the effects of thinning on ingrowth. A more detailed discussion of clump and sprout regeneration can be found in the clump and sprout section of this report.

Mortality: Mortality had a definite impact on the study in the first twelve years, especially in the control plots (Figure 4). The wildfires that occurred during the summers of 1985 and 1994 produced very intense conditions and are responsible for the majority of tree death that occurred. A total of three of the 10 control plots were affected by fire between 1984 and 1989, and one control plot was affected between 1989 and 1996. An average of 80.6 trees per acre were lost during the twelve-year interval. This impact is still evident in the 17 year analysis.

Site 1, Cuesta Grade: The majority of trees lost in the second inventory (1989) were in plot 1-2 (control), which lost 215 trees per acre. The 1996 inventory showed a serious loss again in plot 1-2 of 110 more trees per acre. In total, plot 1-2 lost 325 of its 400 trees per acre from 1984 to 1996 due to fire, which is 45% of the total lost in all control plots.

It should be noted that due to rounding, some of the numbers present may appear to differ slightly from the data shown in Tables 3 and 4.

Between 1996 and 2001, mortality began to level off in plot 1-2, with only a net of 5 trees per acre being lost. This includes five trees per acre that were added through in-growth. However, as mentioned above, those five ingrowth trees are the result of a single knobcone pine, not a coast live oak.

Site 3, Arian Ramage: During the 1984 -1989 period, Site 3 was significantly affected by both fire and snow. In plot 3-3, only 30 trees/acre that were damaged by one or both of these events died during the first 5-year period, while an additional 160 trees per acre died during the next 7 years (1989 - 1996). The 2001 remeasurement showed that additional 45 trees per acre died in this plot.

By contrast only an average of 30 trees/acre died from other causes in the other seven control plots for the 1984 - 1996 period. Also, only an average of 2.1 and 0.7 trees per acre died in the 100 and 50 sf/acre plots, respectively (Table 4). The greater density of trees in the unthinned control plots certainly contributed to stand altering fire intensity and subsequent loss. The effect of repeated fire in unthinned stands cannot be ignored.

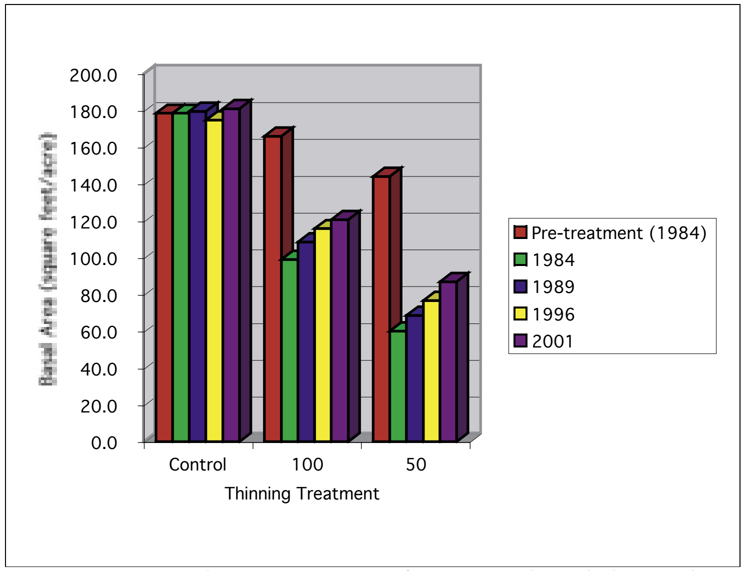


Figure 5. Basal area per acre for control and thinned plots.

Mortality in control plots: Without the presence of fire between the 1996 and 2001 inventories, the mortality rates have begun to decline or level out in the control and treatment plots. The number of stems per acre in the control plots continued to decline slightly but at a much lower rate than measured in previous inventories. The mortality rate for the first five years (1984 - 1989) was an average of 8.3 trees/acre/year. The 12 and 17 year rates (1984 - 1996, and 1984 - 2001) lessened to approximately 6.7, and 5.5 trees/acre/year respectively. The last five-year period of the study (1996 - 2001) had an average mortality rate of 2.4 trees/acre/year, indicating the overall decreasing trend in mortality. In total, an average of 92.8 trees per acre were lost in the control plots over the seventeen-year period. However, 80.6 of these trees were lost in the first twelve years due primarily to the effects of fire. The current (2001 measurement year) mortality rate in the control plots exceeds the ingrowth rate resulting in further decline in stems per acre.

Mortality in 100 sf/ac thinned plots: The mortality rate for the 100 sf/ac plots over the first five-year period was 0.6 trees/acre/year. This rate slightly increased to 0.8 trees/acre/year over the twelve-year period and has maintained this same rate over the seventeen-year period. These plots lost an average of 13.9 trees /acre over the seventeen-year period, with an average of 9.4 trees/acre being lost in the first twelve years. With an ingrowth of 11.1 trees/acre over the last five years, the number of stems per acre is now within 2.8 trees of the original number after thinning.

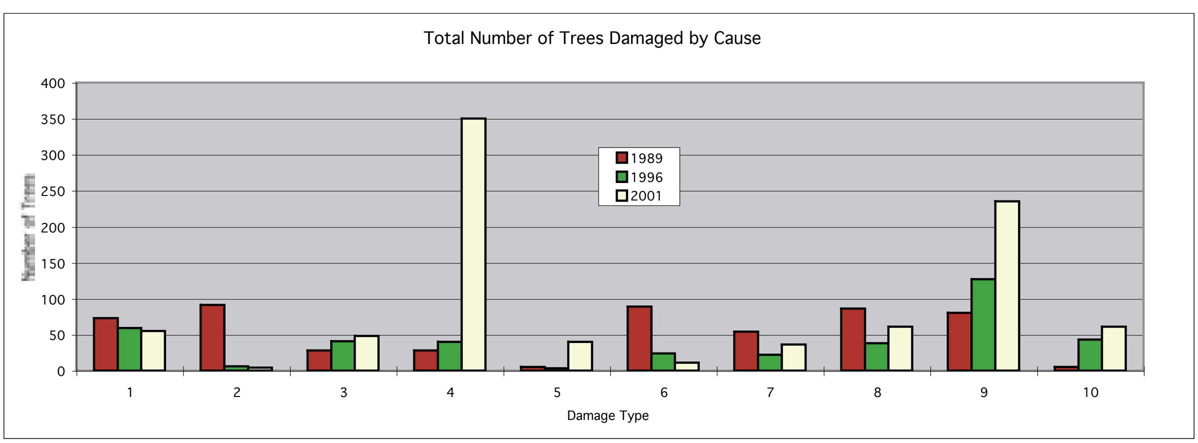
Mortality in 50 sf/acre thinned plots: Mortality rates in the 50 sf/ac plots have been the lowest, by far, of the three plot treatments over the seventeen-year period. The highest rate, 0.4 trees/acre/year, occurred during the first 12-year period, and dropped to 0.3 trees/acre/year after 17 years (Table 3). These plots have only lost an average of 5.6 trees/acre (Table 4) over the 17-year period and have gained 24.4 trees/acre in ingrowth within the last five years, resulting in an increase of about 18.9 trees per acre above the amount after thinning.

Table 5. Number of trees affected by various damage factors, by plot.

Code	Damage Type
1	DT=Dead Top
2	S=Snow Damage
3	BT=Broken Top
4	SS=Sprouts-stem
5	SB=Sprouts-basal
6	SP=Sprouts-other
7	Y=Fire Damage - no diameter effects
8	YD=Fire Damage - effects diameter
9	CB=Cracked Bark
10	BI=Basal Injury

Plot Number	DT	S	BT	SS	SB	SP	Y	YD	CB	BI
Control Plots										
1-2	6	2	6	11	8	1	3	10	2	
2-2	4		2	35		3			19	5
3-3	5		12	38					23	3
4-3	3		3	48	3				27	2
5-2	1		2	8	2				6	
6-2	(site unavailable for data collection)									
7-3	4		3	20		2	3	1	13	4
8-3	6		2	9	1				13	
9-3	2		1	16	7		9	9	10	15
10-2			3	15			2	4	13	1
2001 Subtotal	31	2	34	200	21	6	17	24	126	30
1996 Subtotal=	34	2	27	7	0	19	14	27	57	18
1989 Subtotal=	38	26	7	4	4	55	31	44	43	2
100 sf/ac Plots										
1-1	23		1	1		2	9	22		1
2-3				6		2			11	1
3-2		2	4	9					8	7
4-1				18	3				11	1
5-3				3	1		1	1	8	2
6-3	(site unavailable for data collection)									
7-1			1	29					10	1
8-1	1			8					4	
9-1				6	3		2	2	4	2
10-3							3			4
2001 Subtotal	24	2	6	80	7	4	15	25	56	19
1996 Subtotal=	25	2	5	10	0	4	5	2	34	15
1989 Subtotal=	34	38	8	7	1	19	18	32	24	3
50 sf/ac Plots										
1-3			3	10	3		2	5	4	2
2-1				2					8	1
3-1			4	26	6				17	4
4-2				6		1			4	
5-1				3			1	1	4	
6-1	(site unavailable for data collection)									
7-2			1	2				2	7	2
8-2				10	1			2	3	1
9-2				7				2	2	1
10-1				4	2		1		4	1
2001 Subtotal	0	0	8	70	12	1	4	12	53	12
1996 Subtotal=	0	2	9	23	3	1	3	9	36	10
1989 Subtotal=	1	27	13	17	0	15	5	10	13	0
1989	73	91	28	28	5	89	54	86	80	5
1996	59	6	41	40	3	24	22	38	127	43
2001	55	4	48	350	40	11	36	61	235	61

Figure 6. As noted, the incidence of damage types appears to have decreased. This is because most of the trees that were affected in the 1989 inventory died by the 1996 inventory.



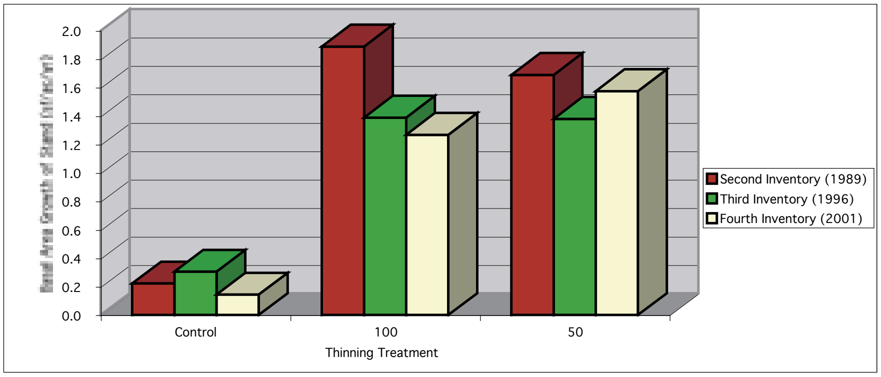


Figure 7. Basal area growth of stand for control and thinned plots.

In addition to the outright death of trees from fire, a number of other factors contributed to tree damage during this period (see Table 5 and Figure 6). Again, wildfire played an important role. Many trees had scorched trunks, burned crowns and cracked or swollen bark, making diameter measurements difficult. Trees which were defoliated by the flames often produced sprouts along the stem and branches. Although they were classified as living trees, their rate of growth will be greatly reduced.

Basal Area per Acre

Basal area was the variable used to design the thinning treatments in 1984. The changes that have occurred are shown in Figure 5.

The seventeen-year average increase for all control plots is 2.5 sf/ac, or about 1.4%, for the 17-year period. The more heavily thinned (50 sf/ac) plots increased by about 26.8 sf/ac (45%) while the 100 sf/ac increased by about 21.6 sf/ac (22%) over the same time period. These growth rates have all increased from the 1996, twelve-year average.

Throughout the seventeen-year period, the 50 sf/ac plots have continually increased in growth rate (sf/ac/yr) and have now surpassed the 100 sf/ac plots in basal area production. Within the first five years, the 100 sf/ac plots out-produced the 50 sf/ac by only 0.2 sf/acre/yr. The 12-year results showed that the 50 sf/ac treatment plots were virtually even in growth with the 100 sf/ac plots. In the 2001 inventory the 50 sf/ac plots showed an increase of 0.3 more sf/ac/yr than the 100 sf/ac plots (17 year average).

This may be an indication that the trees in the 100 sf/ac plots are beginning to more fully occupy the site, and as a result, their growth rates are beginning to slow. The trees in the 50 sf/ac plots continue to benefit from increased soil nutrients and sunlight available after thinning.

Further, for the 17 year inventory, these data show that the 50 sf/ac plots averaged 11 times the basal area growth when compared to the control plots (Figure 7), and the 100 sf/ac plots averaged 9 times the growth compared to the control plots.

It could be argued that these ratios and data might be somewhat skewed because of the high rates of mortality in the control plots over the first twelve years. On the other hand, one of the reasons for thinning a stand is to reduce the density quickly, i.e., speed up the rate of natural mortality, and to improve the vigor and growth rates of the remaining trees. Dense stands will typically have higher rates of natural mortality as well as higher death rates during catastrophic events such as wildfire and extreme snowstorms. Therefore, the analysis from this point on is only conducted on living trees. This is to compare growth rates on live

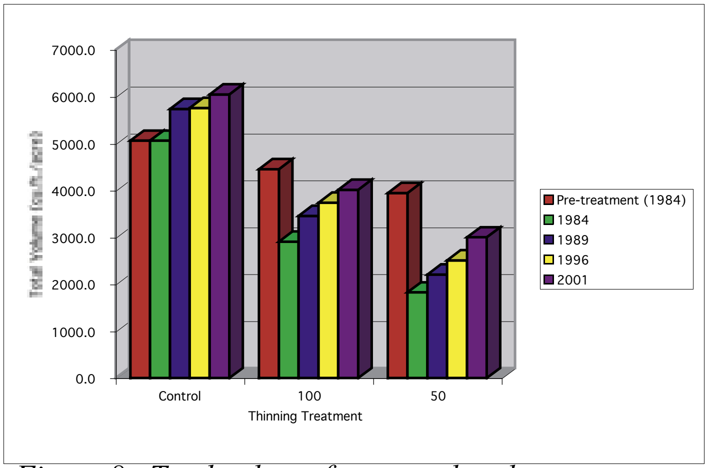


Figure 8. Total volume for control and treatment plots.

trees only, rather than all trees that include both live and dead trees.

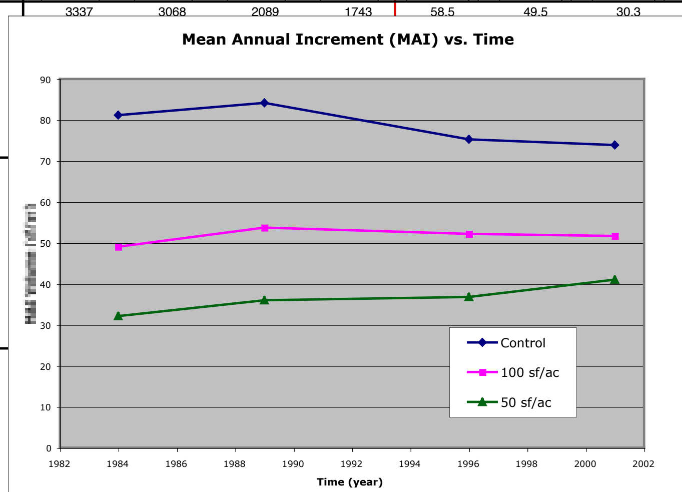
Because of the mortality caused by fire and snow, these data show not only the positive results of thinning but also the loss of growth that can occur when stands are not properly managed.

Total Volume in Cubic Feet per Acre

During the seventeen-year period, total volume increased by 983.9 cf/ac (19.4%) for control plots (Figure 8). Thinned plots incremented by 1,106.5 cf/ac (38.1%) for the 100 sf/ac plots, and by 1,173.9 cf/ac (64.2%) for the 50 sf/ac plots.

As with basal area, the 50 sf/ac plots are beginning to out-produce both the control and 100 sf/ac plots in total volume growth after 17 years. In the twelve-year results the 50 sf/ac plots were actually the least productive, with 682.5 cf/acre. Both the control and 100 sf/ac plots out-produced the 50 sf/ac plots with 695.8 and 835.2 cf/ac of total volume, respectively. This shift in total volume production to the 50 sf/ac plots shows the ability of the residual trees to gain volume as a benefit from thinning. As the stand gets older, the site production continues to increase until it reaches its original equi-

CONTROL Plot number	2001 age (years)	Post-treatment 1984 Tot. vol (cu. ft/acre)	1989 Tot. vol (cu. ft/acre)	1996 Tot. vol (cu. ft/acre)	2001 Tot. vol (cu. ft/acre)	MAI (1984) (cu. ft/acre/yr)	MAI (1989) (cu. ft/acre/yr)	MAI (1996) (cu. ft/acre/yr)	MAI (2001) (cu. ft/acre/yr)
1-2	74	3337	3068	2089	1743	58.5	49.5	30.3	23.6
2-2	71								108.2
3-3	46								79.9
4-3	83								134.3
5-2	95								95.6
7-3	106								29.7
8-3	92								80.5
9-3	103								61.6
10-2	82								51.3
	84								73.8
100 SF/AC									
1-1	60								39.4
2-3	80								55.0
3-2	46								69.3
4-1	71								70.4
5-3	96								54.8
7-1	91								30.4
8-1	88								50.4
9-1	104								45.3
10-3	80								50.0
	80								51.7
50 SF/AC									
1-3	74								27.1
2-1	71								39.0
3-1	42								100.4
4-2	82								46.8
5-1	93								31.3
7-2	106								18.0
8-2	92								35.3
9-2	99	2450	2953	3156	3760	29.9	33.9	33.6	38.0
10-1	71	1619	1805	2134	2369	30.0	30.6	32.3	33.4
	81	1828	2211	2510	3002	32.1	36.0	36.8	41.0



1985 Pillsbury & De Lasaux study

Plot Number	Age (years)	Ave. Vol Growth (cu. ft/acre/yr)
1	111	23.29
2	131	37.78
3	73	52.55
4	79	77.52
5	72	49.88
6	73	43.94
7	105	21.78
8	92	44.89
9	92	62.57
10	68	103.64
11	60	86.65
12	79	79.57
13	60	73.53
14	72	80.19
15	73	21.09
16	109	28.40
17	95	35.73
18	91	54.74
19	56	82.63
20	129	44.74
21	60	78.67
22	57	75.88
23	45	108.37
24	106	56.01
25	43	64.71
Ave=	81.2	59.55

Table 6. Plot age, total volume and MAI (mean annual increment) for two coast live oak studies on the central coast of California.

librium. The results of this are just beginning to be seen after 17 years of residual growth. Even though the heavily thinned plots have fewer trees than the other plots, the growth production needed for the site to reach equilibrium is now being dispersed among these fewer but larger trees, resulting in an increase in growth and merchantable volume in the 50 sf/ac plots.

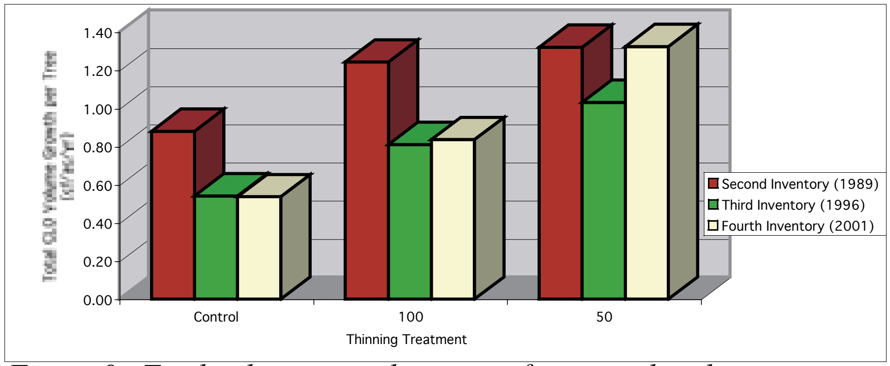


Figure 9. Total volume growth per tree for control and treatment plots.

Although the seventeen-year results show the thinned plots as being the most productive, it must be understood that because control plots contain many more trees than the thinned plots, the total volume growth could be greater simply due to the total number of trees. In total, they could produce more volume even though their growth rates might be slower. For this reason, a more realistic comparison of growth is to calculate average growth per tree.

Using this approach, the data show that the thinned plots out-grew the control plots by substantial margins (Figure 9). The 100 sf/ac plots increased 56% more total volume, and the 50 sf/ac plots incremented 147% more total volume than did the control plots.

The U.S. Department of Agriculture-Forest Service, 1977 uses the following definition for Productive Forest Land: “Land which is physically capable of producing crops of industrial wood in excess of 20 cubic feet/acre/year.” While the wood products from coast live oak are mostly in the form of firewood, it is interesting to note that the rate of growth of coast live oak exceeded 20 cubic feet/acre/year for all plots, except one.

The results of this study were compared with a stem analysis study conducted on 25 plots in 1985 (Pillsbury and De Lasaux) with similar results. All plots in the 1985 study exceeded 20 cubic feet/acre/year based on the mean annual increment (MAI).

Based on the graph, embedded in Table 6, it appears that the MAI of control plots has peaked and is now declining while the MAI of the 50 sf/ac plots is still increasing. The MAI of the 100 sf/ac plots appears to be leveling off. The next measurement should provide a clear indication of the MAI trend for these plots. Thus the overall productivity of non-thinned plots will likely continue to decrease, however, cutting treatments of the thinned plots has prolonged stand productivity.

Wood Volume and Sawlog Volume in Cubic Feet per Acre

Wood volume increased at a higher rate in the thinned plots than in the control plots over the seventeen-year period. The 100 sf/ac plots increased by about twice as much as the control, while the 50 sf/ac increased by more than three times as much (see right-most column for 17 year growth data in Table 7; also Figure 10). On the other hand, sawlog volume in the 100 and 50 sf/ac plots only increased by about 4% and 8% more, respectively, than the control plots (see Table 7 and Figure 10).

This is because trees having sawlog volumes are larger and already dominate the crown and root space in the stand. Consequently, their growth rates are not yet as greatly increased by thinning in the first 17 years compared

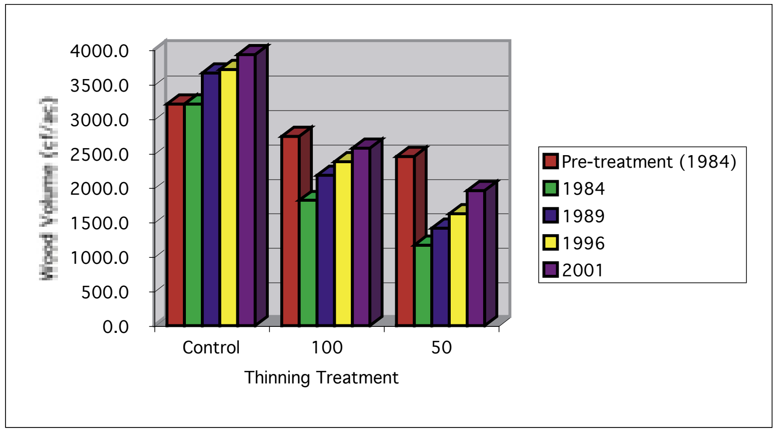


Figure 10. Wood volume per acre by treatment.

Wood Volume		Five-year growth data			Twelve-year growth data			Seventeen-year growth data		
	Volume	Volume	Percent of	Percent of	Volume	Percent of	Percent of	Volume	Percent of	Percent of
	Thinned	Increment	Thinned	Volume	Increment	Thinned	Volume	Increment	Thinned	Volume
Treatment	(cf/ac)	(cf/ac)	(cf/ac)	(cf/ac)	(cf/ac)	(cf/ac)	(cf/ac)	(cf/ac)	(cf/ac)	(cf/ac)
Control	0.0	454.3	n/a	14.1	502.9	n/a	15.7	719.3	n/a	22.4
100 sf/ac	925.3	363.3	39.3	20.0	561.0	60.6	30.9	756.2	81.7	41.6
50 sf/ac	1287.7	253.0	19.6	21.7	459.1	35.7	39.4	793.6	61.6	68.2

Sawlog Volume		Five-year growth data			Twelve-year growth data			Seventeen-year growth data		
	Volume	Volume	Percent of	Percent of	Volume	Percent of	Percent of	Volume	Percent of	Percent of
	Thinned	Increment	Thinned	Volume	Increment	Thinned	Volume	Increment	Thinned	Volume
Treatment	(cf/ac)	(cf/ac)	(cf/ac)	(cf/ac)	(cf/ac)	(cf/ac)	(cf/ac)	(cf/ac)	(cf/ac)	(cf/ac)
Control	0.0	162.2	n/a	20.9	204.8	n/a	26.4	262.4	n/a	25.3
100 sf/ac	83.6	67.0	80.2	19.9	102.1	122.2	30.3	143.0	171.1	29.8
50 sf/ac	225.2	49.0	21.8	19.4	78.0	34.6	30.9	125.2	55.6	33.1

Table 7. The effects of thinning on wood and sawlog volume in coast live oak.

to the changes in total and wood volume. It will take more time before smaller trees will grow into the sawlog category and therefore increase the total sawlog volume.

Greater changes are expected during future inventories. However, it should be noted in Table 7 that 59.4 cf/ac more sawlog volume has already grown back in the 100 sf/ac plots than was removed. The 50 sf/ac plots are also increasing at a steady rate and are within 100 cf/ac of what was originally removed. This is illustrated in Figure 11.

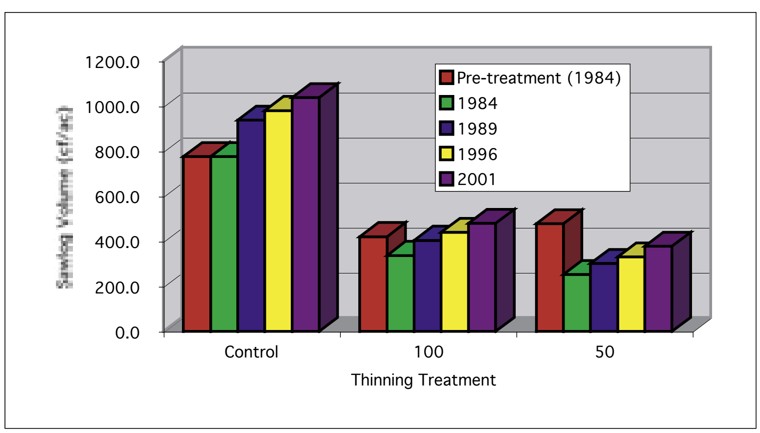
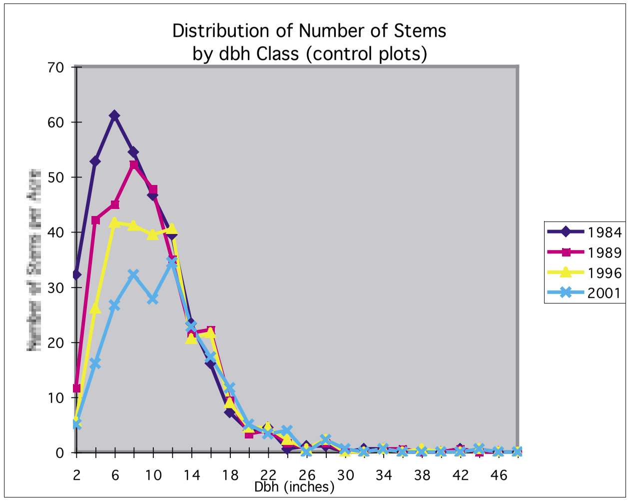


Figure 11. Sawlog volume per acre by treatment.

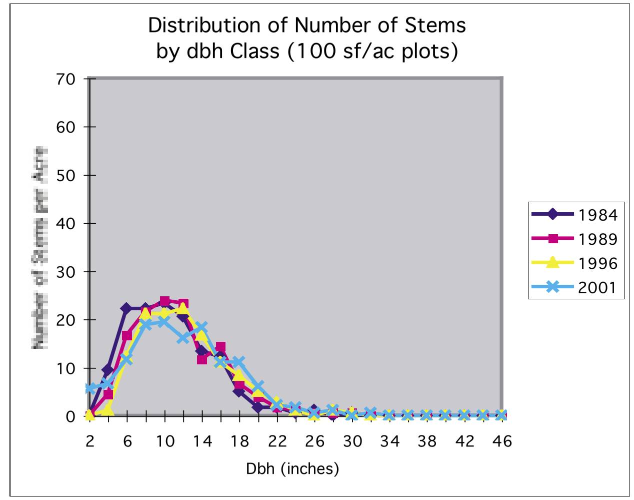
Tree Movement by Diameter Class

Another important facet of the study is to examine how trees "move," that is, how their

A. (Control plots)



B. (100 sf/ac plots)



C. (50 sf/ac plots)

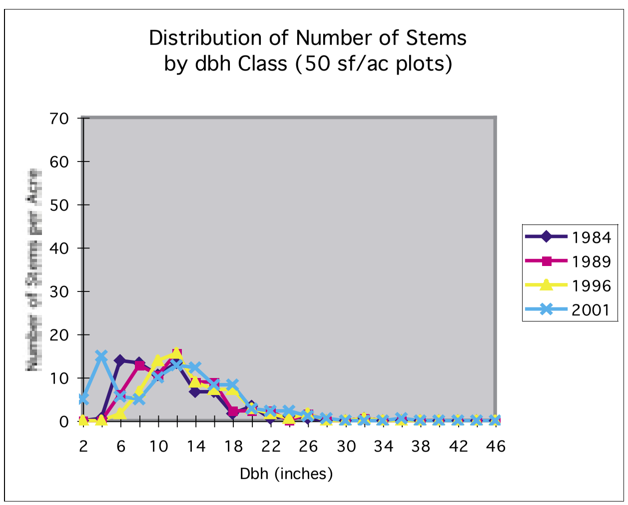
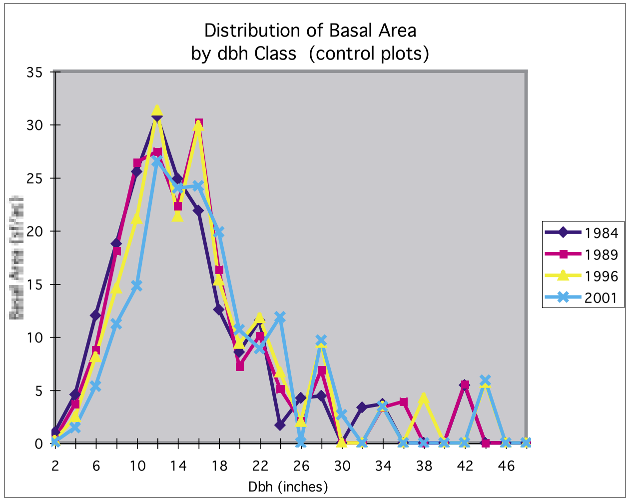


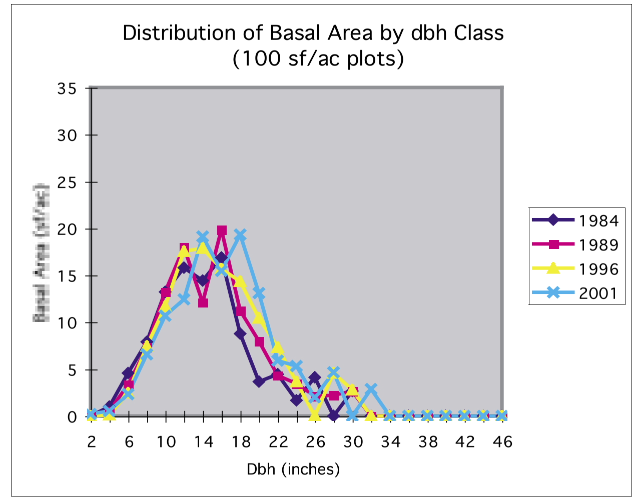
Figure 12 (a, b, c). Stand graph showing the distribution of number of stems per acre by diameter class.

Among the three graphs in Figure 12, there is a common pattern of movement. The smaller stems are moving, as expected, into the larger diameter classes. The significant reduction in the peak of the number of stems per acre for the control plots is a reflection of the mortality that has occurred over the past 17 years. In the thinned plots, there is a general movement towards more stems per acre, evidenced in Figure 12 b and c. Ingrowth is shown in 12c for 2001 (see small diameter classes). As more ingrowth occurs in the future, we should see more stems per acre in the smaller diameter classes.

A. (Control plots)



B. (100 sf/ac plots)



C. (50 sf/ac plots)

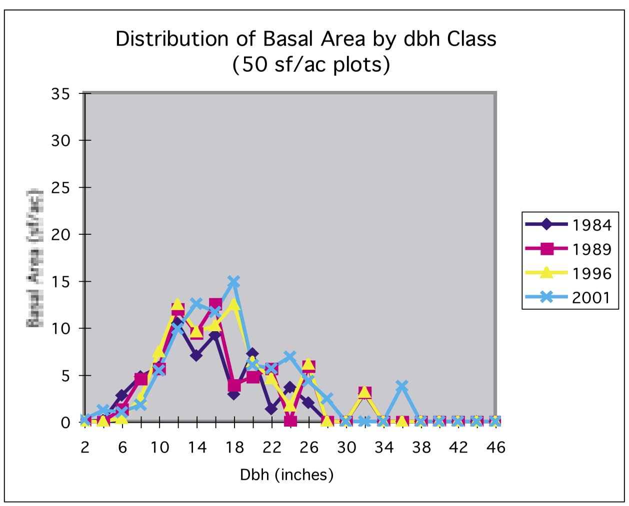
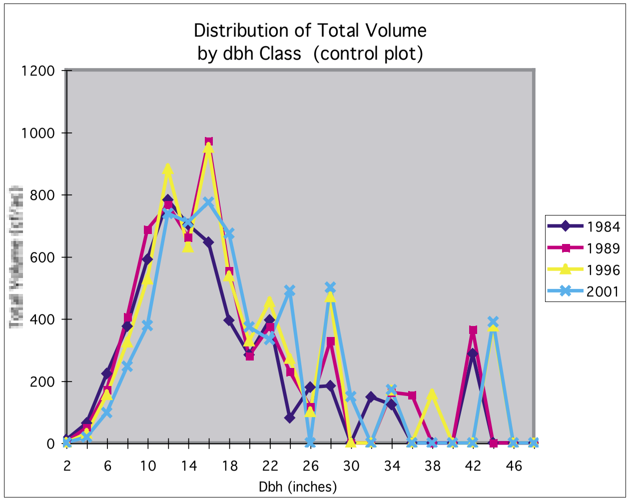


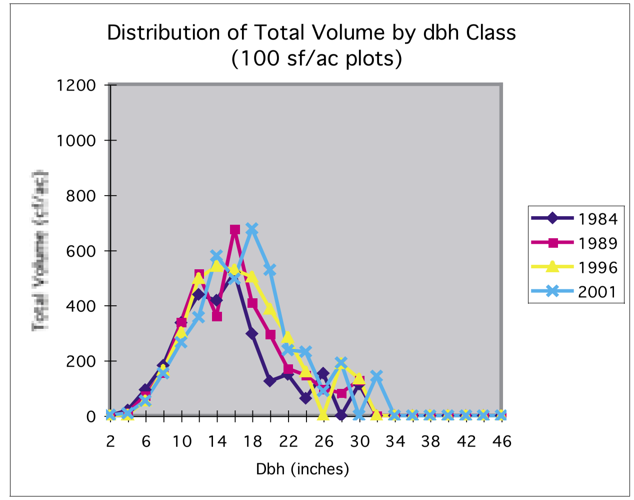
Figure 13 (a, b, c). Stand graph showing the distribution of basal area per acre by diameter class.

In Figure 13, we see a strong correlation between the basal area and total volume graphs (Figure 14). As is expected, there was a smaller basal area increase in the control plots than in the thinned plots. The greater increase in the thinned plots is a result of less crown density and increased vigor brought about by the treatments.

A. (Control plots)



B. (100 sf/ac plots)



C. (50 sf/ac plots)

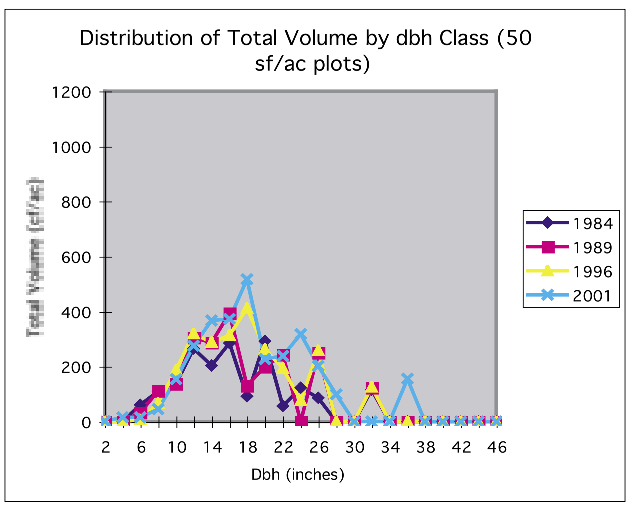
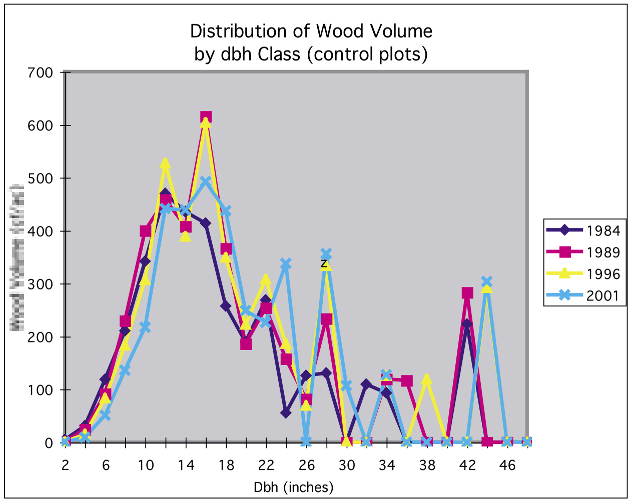


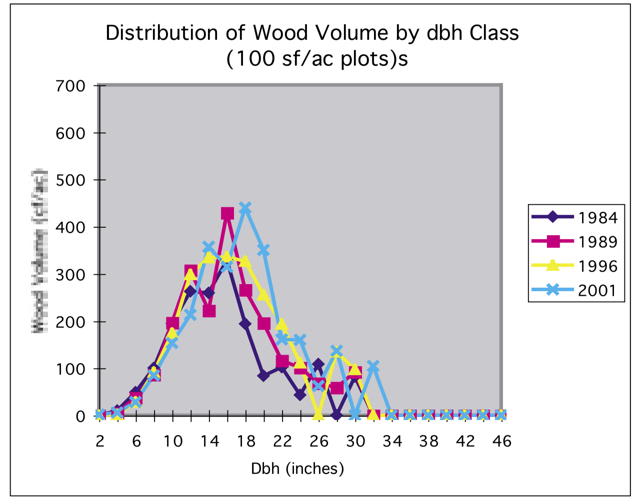
Figure 14 (a, b, c). Stand graph showing the distribution of total volume per acre by diameter class.

The majority of the volume growth for all treatments is in the mid- to -large-sized diameter classes. Very little growth can be seen in the small- to mid-sized diameters (2-10" dbh). This suggests that the thinning presciption used, i.e, a combination improvement cut and low thinning, is the appropriate strategy for coast live oak stands.

A. (Control plots)



B. (100 sf/ac plots)



C. (50 sf/ac plots)

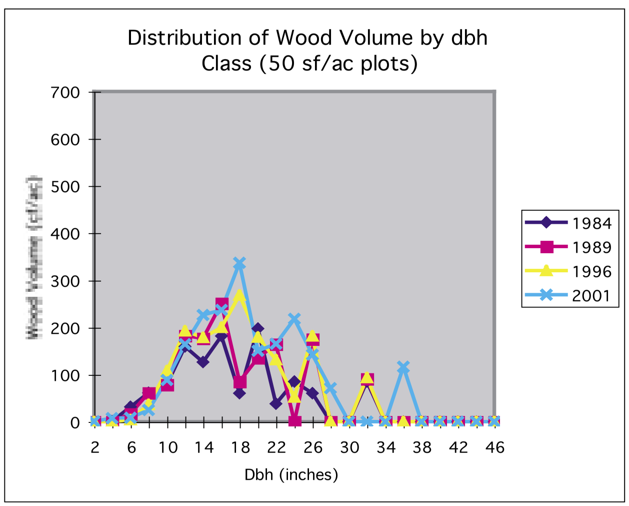
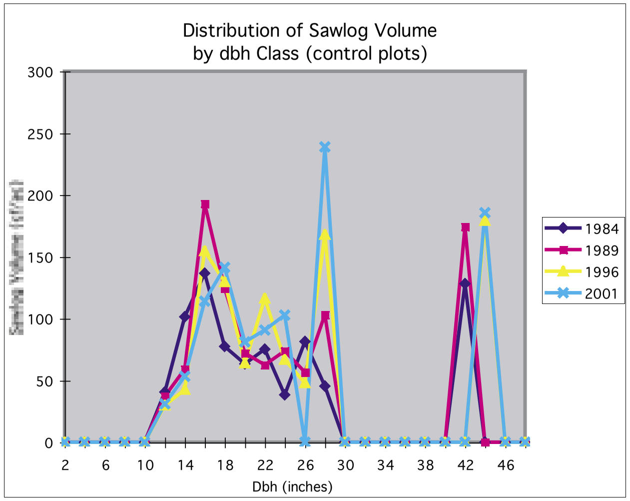


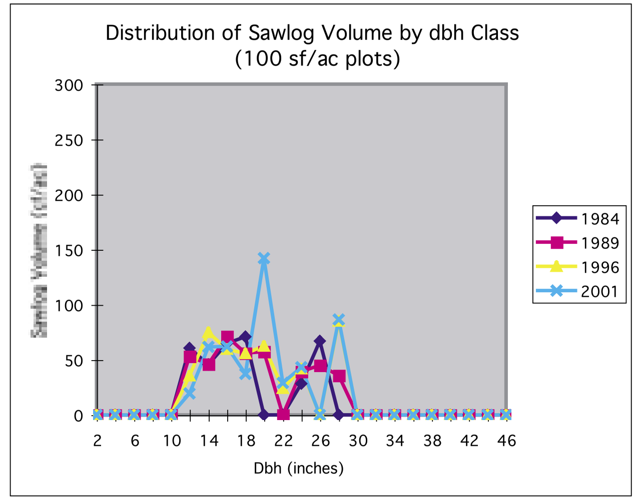
Figure 15 (a, b, c). Stand graph showing the distribution of wood volume per acre by diameter class.

The plots thinned to 50 sf/acre show the greatest increase in wood volume over the last 17 years. There is some significant growth increases in the 100 sf/acre plots but in the control plots there is little increase in wood volume.

A. (Control plots)



B. (100 sf/ac plots)



C. (50 sf/ac plots)

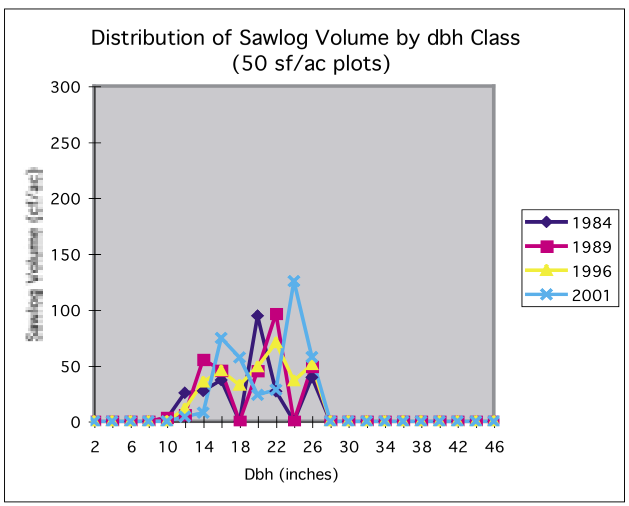


Figure 16 (a, b, c). Stand graph showing the distribution of sawlog volume per acre by diameter class.

The larger diameter trees were the only ones to show an increase in the control plots. In the 50 sf/acre and the 100 sf/acre plots the sawlog volume has slightly increased.

diameter classes change in relation to the rest of the stand. Figures 12-16 illustrate the changes that occurred and the regrowth trends that are beginning to appear. The diameter classes that were initially removed in 1984 were primarily in the 2-13 inch dbh range.

Figures 12 through 16 show the movement of trees for each treatment along with a short discussion.

ECONOMIC INCENTIVES FOR MANAGEMENT

The oak woodland ecosystem covers a large area both throughout the nation and in California. When viewed from a complete economic perspective, the benefits and values of this ecosystem are as large as any other forested ecosystem, even though it is not known for its commercial wood commodity value. Historic values for oak woodlands have been derived from their contribution to rangeland quality, firewood, and wildlife habitat. Increasing urbanization of the oak woodlands of California has raised their value with respect to aesthetic contribution to property value, watershed protection, and open space. Finally, the heightened concern over global climate has created a recognition of the oak woodlands as a sink for carbon (carbon sequestration), a value that is still poorly understood and has yet to be monetized.

Despite these significant values, the size and health of California's oak woodlands are severely threatened by two major forces — urban sprawl and fire. The pattern of residential development has been biased toward the oak woodlands, especially given their proximity to the major metropolitan areas and their value for home sites. The conversion value to such development is far greater than any alternative market value provided by oak woodlands. The infrastructure that accompanies this development includes increased fire protection, which allows fuels to build. As we know, fire is a necessary function in sustaining this ecosystem. But suppression to protect property and lives changes the role of fire from an ecosystem-sustaining force to a destructive one.

In this section of the report, we will present information on the growing concern over the fire risk to oak woodlands from urbanization and the associated costs of fire suppression, expenditures which will only grow if not redirected to the sustainable management of oak ecosystems. The silvicultural prescriptions presented earlier are an important means of "fire-safing" live oak stands and are adaptable to other oak types. However, the funds needed to invest in this management regime results in costs that may be too high to justify the intense level of thinning it requires. New thinning prescriptions that will meet the goals of sustainably fire-safing the landscape need to be developed so that thinning costs would represent a smaller fraction of the funds spent on fire-fighting on these lands and will return to society the benefits currently being destroyed.

Wildland-Urban Interface

The range of coast live oak (*Quercus agrifolia*) and interior live oak (*Quercus wislizenii*) extends along almost the entire coast of California and inland throughout the foothills of the Sierra Nevada mountain range (see Figure 17). These species are often found in association with numerous hardwood and coniferous species.

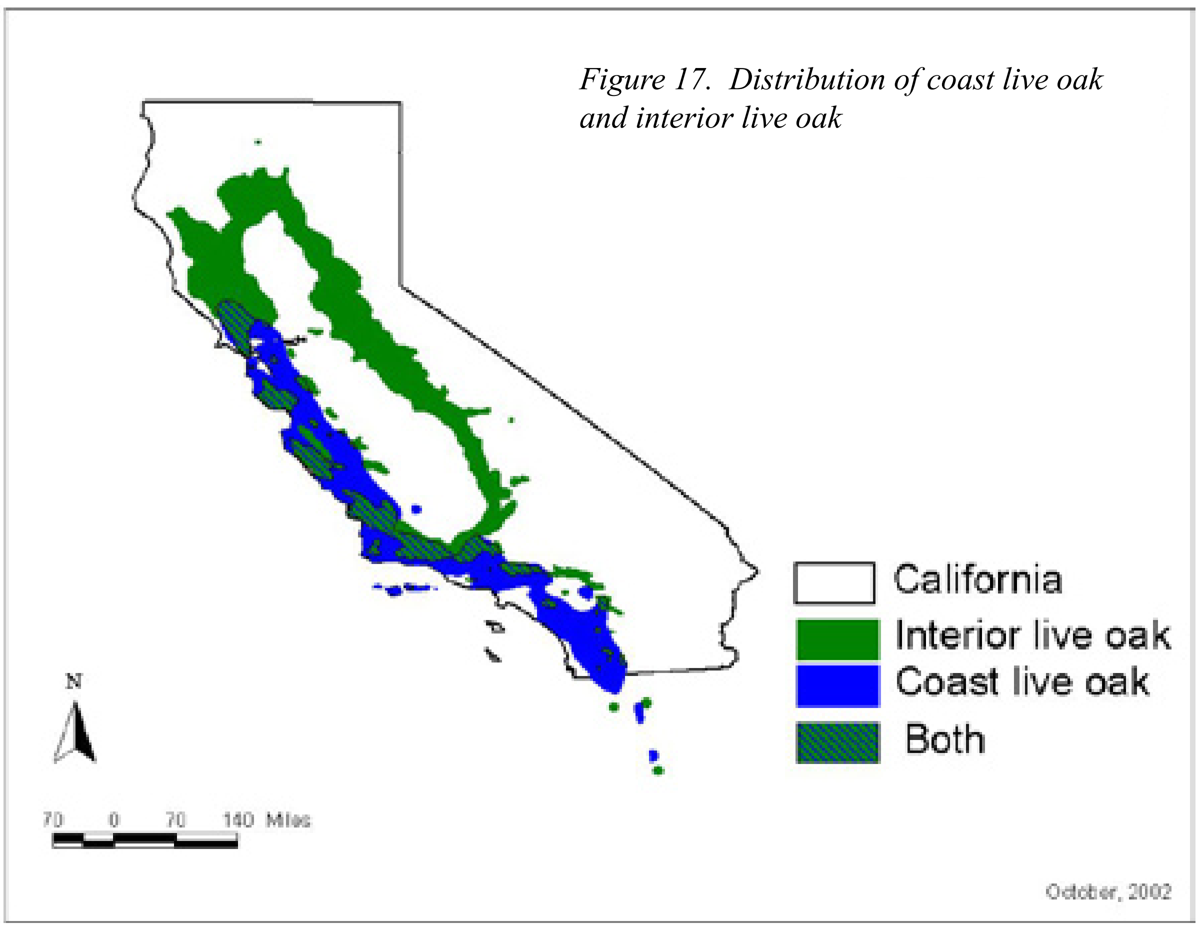
The location of urban areas and more recent urban sprawl correlates almost perfectly with these live oak forests. Nearly 90 percent of Californians live in coastal counties, having increased by 87 percent since 1960 (Office of

Ocean Resources Conservation and Assessment 2002). The preferred, or usually only suitable, location for homes in these lands are in the aesthetically pleasing environments offered by oak woodlands. More recently, development pressure has extended from the cities of the Central Valley into the Sierra Nevada foothills where oak woodlands dominate the landscape. The pattern of urban sprawl into these formerly wildland ecosystems has created what is now commonly referred to as the wildland-urban interface (WUI).

Definition of the WUI is problematic. These interface lands are perhaps better defined as a condition rather than a land use type, wherein low to medium density housing and related infrastructure mixes with a now-fragmented forest environment. These conditions include forest-containing patches of widely spaced tracts of dense housing (urban enclaves), closely spaced housing with pockets of natural forest (natural area fragments), conditions where densely spaced housing abuts large tracts of natural forest (urban fringe) (Nickles 2002).

The California Department of Forestry and Fire Protection (CDF) has other designations that relate more to the fire-risk condition of the oak woodlands. CDF refers to clusters of homes and related structures along a fringe of developed area that are vulnerable to wildfire as the classic interface. However, a more common condition occurs where rural homes are intermixed within a forested/vegetated landscape — the mixed interface. The mixed interface retains much of the character and values provided by the wildland ecosystem

Figure 17. Distribution of coast live oak and interior live oak



	Developed	% of Calif.	Undeveloped	% of Calif.	Mixed Interface	% of Calif.
Non-flamable	4,858,000	4.8	1,338,160	1.3	11,033,320	10.8
Potentially Flamable	9,257,440	9.1	39,911,240	39.1	35,656,240	34.9
Total	14,115,440	13.9	41,249,400	40.4	46,689,560	45.7

Table 8. Distribution of CDF Land Use Classifications by potential flammability.

and may become more valuable as habitat for rare and listed wildlife species as population expands (CDF, Fire Management of California Ecosystems 2000).

Today, these mixed interface lands are the focus of fire risk assessment. In fact, here in California, the delineation of the WUI is increasingly a function of fire risk. Developed lands, where housing density is greater than one house per five acres and within about one mile of such developed areas, have received the greatest attention for fire protection. Undeveloped lands – less than one house per 160 acres and located more than three miles from more dense housing – will continue to be managed under wildland fire policy with the lowest fire suppression cost per acre. Mixed interface lands have been identified in the National Fire Plan and by CDF as the lands at greatest risk of fire given their proximity to the developed lands. Table 8 presents CDF's land areas assessed as "potentially flamable" under these three categories.

As the information in Table 8 illustrates, the mixed interface lands represent about 35% of the potentially flammable lands in California. When the ownership pattern of mixed interface lands is incorporated, the importance of their fire risk becomes clear. Of the 35.7 million acres of mixed interface lands, over 20 million (56%) are private, including county and city lands which amount to nearly 250,000 acres. For the remaining state and federal lands to be considered mixed interface, they must be situated in proximity to the private mixed interface or developed lands.

Categorizing the mixed interface lands which are high fire risk, into vegetation types, reveals the significance of this land designation issue to coast live oak management. Over 6 million acres (about 17 percent) of the 35.7 million acres of the mixed interface is woodland – a vegetation type typified by oak and other hardwoods.

Landowners and insurers recognize the importance of these risks but currently little change in policy is evident. Occasionally, one hears that a residential community being identified as a particularly high fire risk and in jeopardy of losing fire insurance coverage, but society-wide policy changes have yet to occur. The California Fire Plan (CDF 1995) states that the insurance industry incurs about $1.09 of costs/losses for every $1 of premium received on insured structures in the wildlands. Still, rate schedules have not been fully adjusted to account for differences in insuring WUI versus urban structures.

Public recognition of these fire risks is also increasing, however slowly. In a study of WUI homeowners in northern Michigan, sample households recognized the risk and were either willing to pay cash one time to reduce fire risks or were willing to engage in landscape alterations to create a defensible space. However, there were significant institutional, economic, and cultural constraints that prevented a broad willingness to adopt these measures, suggesting that public support is required in order to be effective for management (Winter and Fired 1997).

Growing Fuels Problem

Fire suppression efforts since the early 1900s have altered fire recurrence intervals and affected forest structure and density in oak woodlands. Fire regimes in recent centuries were characterized by frequent, low-intensity fires (USDA FS GTRRMRS-GTR-42 Vol. II, 131 2000). Forest structure in live oak woodlands at that time was generally even-aged with little or no live understory while more open stands of oak species such as blue and valley oak likely contained a developed understory of grasses and woody shrubs. Since the early 1900s, the suppression of fires has allowed for the buildup of fuels in the form of ever-increasing densities of multiple fuel layers. In addition, forest structure has been altered by the suppression of fire. Arrangements of fuels are found in multiple layers reaching from the ground upward to the crowns of the oaks.

Of the three legs of the fire behavior triangle (fuels, weather, and topography), only fuels, most related to forest structure, is a controllable factor (Agee 1996). Forest structure affects fire behavior, and by altering forest structures, landscapes can be made fire-safe (Agee 1996). Keep in mind that a fire-safe forest is not fireproof but will have surface fuel conditions that limit fire intensity and a lower probability that crown fires will either initiate or spread through the forest. The result is a landscape with a structure such that if a fire started, the fire would be more manageable.

Strategies to limit fire intensity and lower potential fire severity include the management of surface fuels. Thinning is a common strategy to manage surface fuels because it adjusts fuel arrangement (forest structure) to produce a less flammable fuelbed. Thinning also "introduces" live understory. For this study, this strategy was most obvious in the heavily thinned plots with the area of woody shrubs steadily increasing in each re-measurement from 27 percent in 1984 (pre-treatment) to 46 percent in 2001. In addition, thinning is a common strategy to manage crown fuels to prevent crown fire patterns (Stephens 1998).

By preventing the conditions that initiate crown fires or preventing the conditions that allow the spread of crown fire, the chance of crown fire, and/or blowup fires, is very low (Agee 1996), (Agee et al. 2000). If this can be achieved across the entire landscape, the possibilities of blowup are significantly reduced (Wilson 1998). By reducing the chances of crown fires, wildfire damage will be reduced compared with unmanaged areas. Furthermore, in managed areas, structures are more easily defended by wildland firefighters, the risks to firefighting personnel are reduced, and the costs of suppression are lower than unmanaged areas.

Oak woodlands historically had low fire intensity regimes where fires burned frequently and as a result remained ground fires with only occasional crown fires. However, efforts in recent decades to suppress fires have disrupted this cycle, giving rise to more dense and thus crown fire-prone conditions. These areas should have the highest priority for treatment across the landscape, with vegetation types that traditionally had high fire regimes having lower priority.

The expanding WUI (mixed interface lands) are the dominant lands at risk for fire (CDF 1995). Currently, there is a lack of economic incentives for private landowners to manage oak woodland resources sustain-

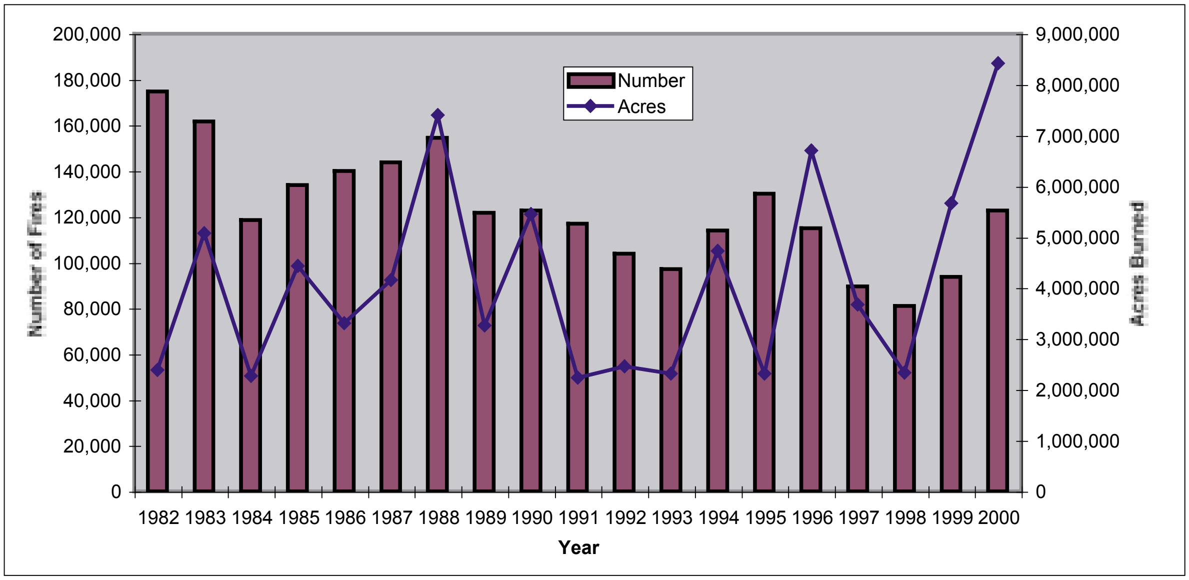


Figure 18. Annual number of wildland fires and acres burned, 1982 - 2000.

ably and in a fire-safe manner. Oak woodlands historically were synonymous with open rangeland with little to no rental value. Why manage a resource for little financial return? Yet these lands are increasingly the focus of intense fire hazard assessments being conducted on the national, state, and local levels due to their unmanaged condition. The active suppression of fire in these woodlands has resulted in conditions ripe for catastrophic wildfires that could result in the destruction of the resource while jeopardizing people's lives, homes, and structures.

<u>Fire Suppression Costs</u>

It is not an exaggeration to say that the concerns over increasing fire danger, especially in the West, have gained national attention and are high on federal and state policy agendas. The frequency and intensity of wildfires has grown dramatically in the last few years, and risk assessments indicate the trend will continue (National Fire Plan 2002). The chart in Figure 18 shows the trends in fire size and frequency. Wildland fires show a tendency in recent years toward fewer but larger fires with the consequent greater risks and costs. Figure 19 supports this conclusion by showing the dramatic increase in suppression costs.

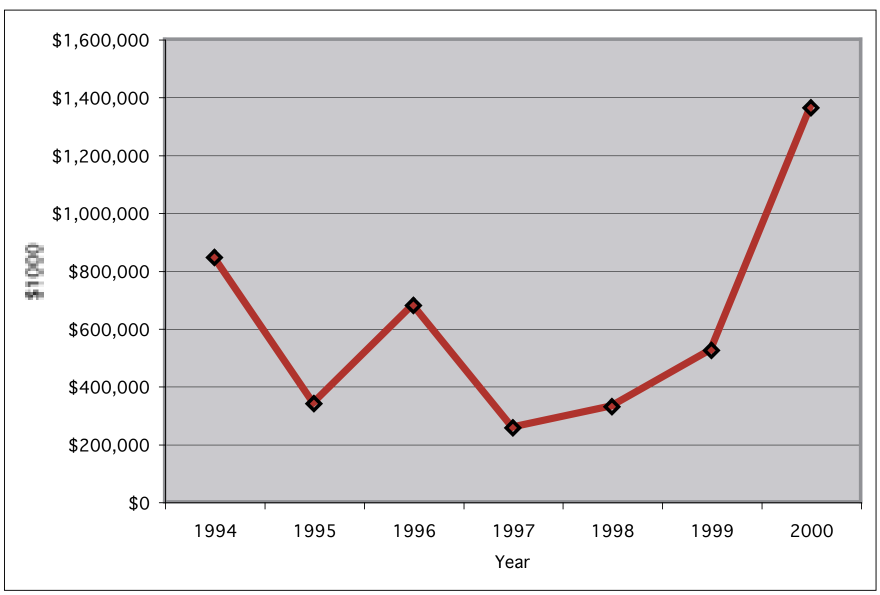


Figure 19. Annual suppresion costs, 1994 - 2000.

Both the National and California Fire Plans conclude that this trend will worsen unless significant resources are committed to reducing the fuel build-ups on the wildlands and mixed interface lands. This is exemplified by the fact that in the U.S., there are 11,376 communities in the WUI that are at high risk from wildfire (Federal Register, Vol. 66, No. 160. no date).

To determine the average suppression costs per acre is problematic given the variation in suppression strategies, tactics and assets employed, risks to property or human life, and many other variables. For instance, in 2000, one of the worst fire years on record, the average suppression cost per acre (from Figures 18 and 19) would be about $175 per acre. In comparison, a fire in the high risk, mixed interface category can cost as much as $1,000 per acre, as in the 4500-acre Ranch Fire (California Forest Stewardship Program 2002). In such catastrophic fires, with their high fuel loads, entire forests are lost, soils destroyed, and eroded away. The result is massive ecosystem destruction that requires an extremely long time or massive expenditures to return to a forested condition.

On the other hand, costs of pre-fire fuel reduction projects are far less — $38 per acre for mechanical pre-treatment and a prescribed fire (California Forest Stewardship Program 2002). These management tools preserve the forest, reduce the risks to property and life, maintain ecological processes and functions, and avoid the wasteful expenditures on firefighting.

<u>Sustainable Fuel Management in the Oak Woodlands</u>

We conducted an analysis of the growth and yield response of these live oak stands to the thinning prescriptions (Pillsbury, Bonner and Thompson 1998). The results demonstrate that sustainable yields can provide a sufficient return on investment based solely on firewood production. However, the size of the firewood industry is probably insufficient to affect a significant portion of the live oak woodlands and the use of firewood as a fuel is likely to decline in the future given air quality concerns.

In the growth and yield analysis conducted in 1998, it was shown that the growth of younger stands (average age 40) grew about twice as fast as older stands (average age 80) in the first 5 years after treatment. The unthinned (control) plots showed little growth-rate difference between young and old stands. In the remaining 7 years, the growth response to treatment slowed down as the stands become more dense, but the age effect on growth response holds steady. Subsequent analysis of growth-rate differences using the information from the 2001 re-measurement reveals that the data are too variable to draw conclusions 17 years after treatment.

Figures 20a and 20b illustrate the sustainability of these uneven-aged management prescriptions based upon a 15-year cutting cycle. Figure 20a presents the predicted sustained yields for the average stand treated with the light thinning prescription (thinned to 100 sf/ac), while Figure 20b shows the same results for the average stand treated with heavy thinning (thinned to 50 sf/ac). Although in the long run the light thinning generates higher sustained yields than the more heavily thinned stand, the greater initial yield from the heavy thinning prescription produces more immediate benefits in the form of a more fire-safe stand and incomes if the residues are utilized.

<u>Fuel Reduction and Utilization Costs</u>

<u>Coast live oak study prescriptions</u>: Estimated thinning costs using the prescriptions

Figure 20a. Sustained yields from light thinning.

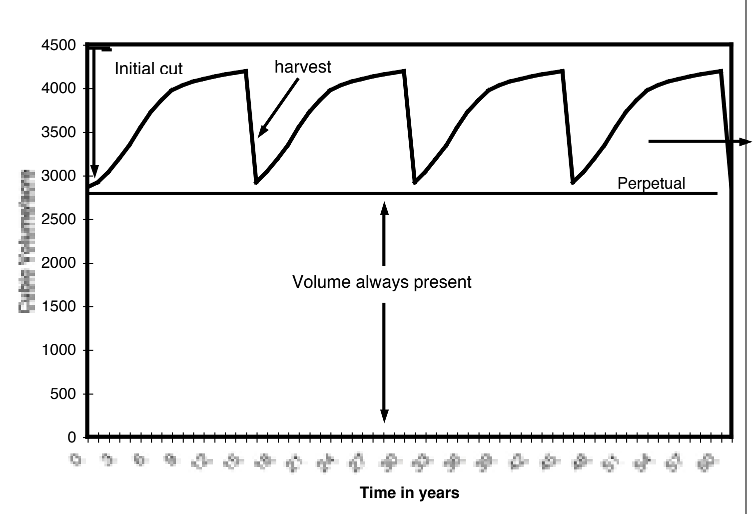


Figure 20b. Sustained yields from heavy thinning.

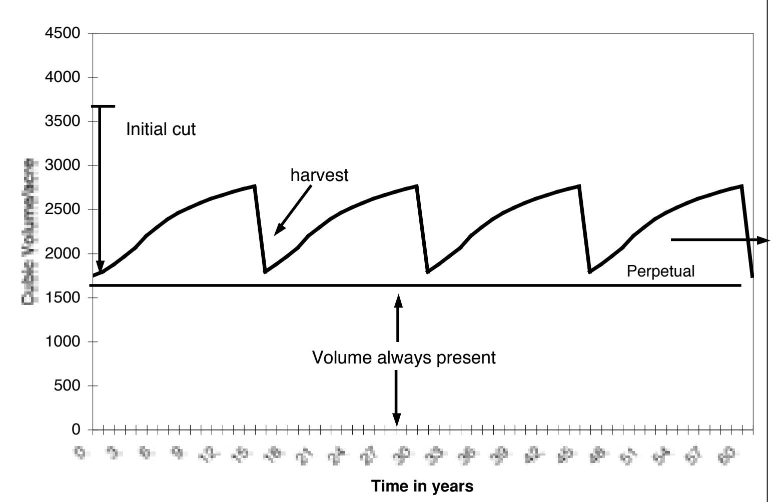


Figure 20. Illustration of the expected yields from a light thinning (a), and a heavy thinning (b).

implemented for this study were developed for both the heavy thin and light thin treatments. The costs were estimated for parcels 10 acres or greater in size. Costs for decking, loading, and clean-up would increase with a smaller parcel size up to nearly double the estimated costs for a parcel of only one acre in size. Felling costs and equipment moving costs would be fixed, although the actual per-acre cost for moving equipment would be reduced with treatments on larger acreages.

For the light thinning prescription, which reduced basal area down to approximately 100 sf/acre, an average of 235 trees per acre removed was used to estimate the costs of thinning. Given a parcel size of 10 acres, it would cost about $2,780 per acre to implement a thinning-from-below prescription. Table 9 illustrates the breakdown of this cost into treatment phases.

Based on this study for the heavy thinning prescription, which reduced basal area down to approximately 50 sf/acre, an average of 252 trees per acre removed was used to estimate the costs of thinning. Given a parcel size of 10 acres, it would cost about $3,375 per acre to implement a thinning from below prescription. Table 10 shows the breakdown of this cost into the various tasks.

These cost estimates could vary based on the species, parcel size, density, and average tree size of the woodland for which a prescription was being written. In addition, these costs were calculated for woodlands in which fuel densities were unnaturally high due to the long history of fire suppression. It is likely that subsequent treatments would incur significantly lower costs.

Trucking or hauling is one more task that could incur a cost. It was assumed that most thinning operations would include a purchaser of the logs to be harvested and that this

Task	Cost per Acre
Felling	$960
Decking	$893
Loading	$422
Clean up	$422
Equipment Moving	$83
Total =	$2,780

Table 9. Thinning Costs – Light Thinning Treatment (10-acre parcel).

Task	Cost per Acre
Felling	$1,120
Decking	$1,116
Loading	$528
Clean up	$528
Equipment Moving	$83
Total =	$3,375

Table 10. Thinning Costs – Heavy Thinning Treatment (10-acre parcel).

person would include trucking costs in his/her bid. For this reason, trucking costs were not calculated on a per-acre basis.

Fire-safe Thinning Prescriptions: Estimated costs of sustainable high-yield silvicultural prescriptions developed for this study resulted in logging costs that are not likely to be justified by returns from wood production (Tables 9 and 10). Somewhere between these high-cost, high-yield prescriptions and doing nothing, resulting in lost ecosystem services, lives, and property, lies a prescription which maintains the oak woodland ecosystem and reduces fire protection/suppression costs. In order to reduce the high costs of implementing intensive thinning prescriptions on a large scale, we looked at altering two variables: thinning design (size and shape) and intensity.

Thinning design on a landscape-level can help to spread costs of treatment acres over some acres that may not need treatment or would require substantially less intense treatment. Intensive thinning could be implemented using a strip design, whereby a wide strip (e.g., 500 feet) of oak woodland could be thinned using an intensive (higher-cost) prescription. The fire-safing effects of strip-thinning could be realized over a greater area than the directly affected treatment area.

Combining an intensive strip-thinning prescription with a less intense prescription focusing only on the reduction of ladder fuels in adjacent areas (versus fuel load reduction) could effectively fire-safe large portions of the landscape. This is accomplished by creating a living "fuelbreak" where, should fire occur in the strip, it would burn as a more easily controlled ground fire as opposed to a highly variable and dangerous crown fire. The effectiveness of a living fuelbreak (also called a shaded fuelbreak) in altering fire behavior (by reducing the size, intensity, and effects of wildland fires) has been shown to be a valuable tool for reducing the risk of catastrophic wildfire (Agee et.al. 2000).

Thinning intensity is the most easily altered factor that can significantly reduce thinning costs. Thinning costs were estimated for a prescription similar to the ones used for this study except that the focus of the thinning prescription would be to first, break the fuel ladder and second, to remove approximately one-third of the wood volume.

Table 11 is provided to show the estimated costs of doing a modified prescription

Task	Cost per Acre
Felling	$320
Decking	$290
Loading	$137
Clean up	$137
Equipment Moving	$83
Total =	$967

Table 11. Thinning Costs – Modified Prescription (10-acre parcel).

with the goal of sustainable thinning to fire-safe the landscape. As you can see, the total cost of about $970 per acre for the modified prescription to fire-safe the landscape is less than half the per acre cost ($2,780) of the light thinning prescription used for the goals of this coast live oak study (Pillsbury, Bonner, Thompson 1998).

Again, this initial thinning cost estimate is likely to be higher than subsequent treatments needed to maintain a fire-safe, sustainable stand structure. Therefore, we estimate an initial cost of about $1,000 per acre and perhaps $500 per acre for subsequent treatments on a 30-year return interval. These expenditure estimates are equivalent to spending about $50 per acre per year, when amortized on a perpetual annual equivalent basis using a 4% real interest rate. Further, the parcel size used to estimate these costs is too small. A more realistic scenario, where defensive thinning strategies would involve patterns of treatments over larger acres, would result in lower per-acre costs. Given these economies of scale, thinning costs could be reduced as much as 50 percent or about $25 per acre per year, annualized. This seems to be a reasonable annual expense by society in order to sustain the oak woodland ecosystem while reducing the risks of catastrophic fire (Reynolds 2002). Existing federal and state cost-share programs are inadequate to modify sufficient acres to have the desired landscape effect (Fire Management for California Ecosystems 2002).

The expansion or development of a cost-share program should only be needed for the short-run since investments in management will result in future state and federal fire suppression cost savings. Portions of these large spending savings need to be redirected to landowners participating in the management program. Suppression cost savings would result from the reduced risk of catastrophic fire, resulting in the safer and easier defense of structures in the mixed interface. Lower intensity fires, should fire erupt in a treated landscape setting, would not result in a significant amount of tree mortality, thus preserving the aesthetic and ecological values of the woodland in these mixed interface areas. This would also result in a cost savings. In addition, oak woodland ecosystems will be healthier and more sustainable (Pillsbury, Bonner, Thompson 1998; Stephens 1998; Wilson et.al. 1998; Agee et.al. 2000; Brown 2000). Fire in the landscape should serve its natural ecological role, while catastrophic fire that destroys resources and properties should be avoided. Thinning can accomplish this objective by reducing the chances of catastrophic wildfire while returning vegetation densities to historical levels similar to those present when fires burned unchecked by humans.

ANALYSIS OF UNDERSTORY DATA

<u>The Concept of Coppice Management</u>

The revegetation of live oaks through the sprouting of cut stumps, otherwise known as coppice management, is widely used in a variety of forestry and woodlot situations. California coast live oak is well known as a vigorous sprouter. This is especially true when damage is created by disturbances such as fire, wind, or harvesting. Most common are sprouts from the cambial layer which form a ring on top of the stump.

In this study sprouts took on two distinct forms: 1) mound or “clump” form and, 2) sprouting form. Clumps occurred when the succulent sprouts were browsed by wildlife or domestic animals. These stump sprouts become rounded into a dome or mound shape. The mounds continue to expand outward, growing mostly in diameter rather than height, until an animal can no longer reach the sprouts in the center, or until a growing season passes when browsing fails to occur. The sprouts in the center of the mound can then "escape" and grow into a new tree. This process could take anywhere from 2 or 3 years up to 15 to 20 years. For the study, if the stump had one or more dominant leaders it was classified as a sprout (as opposed to a clump).

The rapid growth of the sprouts was greatly reduced by browsing of domestic and wild animals. A number of the sites showed evidence of recent activity by domestic livestock. In plots where domestic and wildlife activity is high, the occurrence of clumps was much greater.

In order to better understand the process of tree development from clumps, they were grouped into three size categories: a) clumps less than 2 feet in diameter, b) clumps 2 to 3 feet in diameter and, c) clumps greater than 3 feet in diameter.

Clump Analysis

In 2001, there were a total of 3 clumps in the 100 sf/ac lightly thinned plots; 1 occurred in each of the three categories. In the 50 sf/ac heavily thinned plots there were a total of 13 clumps; 23 percent were less than 2 feet in diameter, 62 percent 2 to 3 feet in diameter, and 15 percent greater than 3 feet in diameter.

It is interesting to note, as can be seen in Figures 21 and 22, that both the lightly thinned and heavily thinned plots showed a substantial decrease in the average number of clumps in 2001 as compared to 1989 and 1996. It can be interpreted that after 17 years, enough time has passed for nearly all of the clump formations to become large enough to allow the escape of a sprout from the center, thus classifying that stump in the sprout category and moving the regeneration closer to the criteria of 2 inches dbh to be noted as ingrowth. Although both treatments showed substantial decreases in the number of clumps, the heavily thinned plots contained 81% of all clumps. This could be the result of lesser crown densities and a longer time to canopy closure.

Sprout Analysis

By definition, a mound ceases to be classified as a mound when at least one sprout attains a height of at least 3 inches and is unbrowsed. Therefore, over time, it would be expected that as mounds begin to produce sprouts, the number of mounds surveyed would decrease and the number of stumps that were

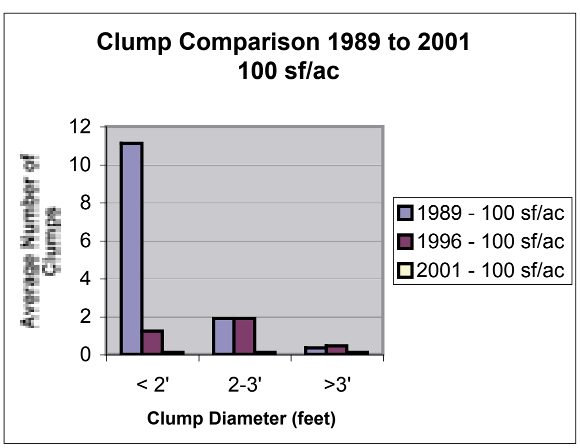


Figure 21. Clump data for 100 sf/ac plots.

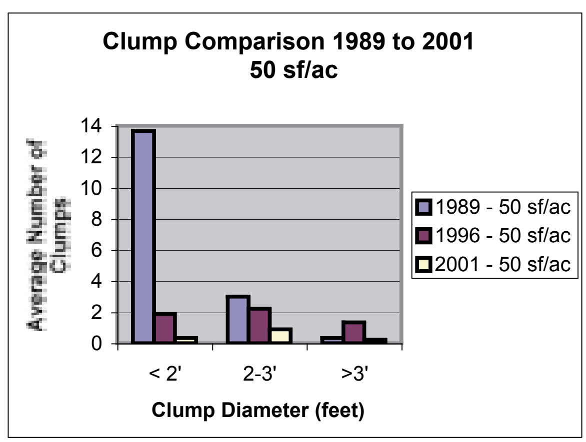


Figure 22. Clump data for 50 sf/ac plots.

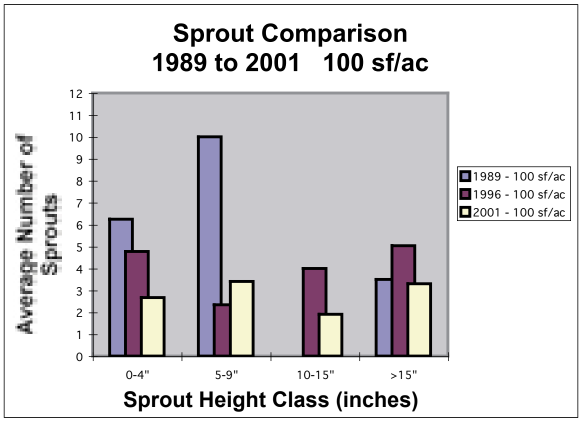


Figure 23. Sprout data for 100 sf/ac plots.

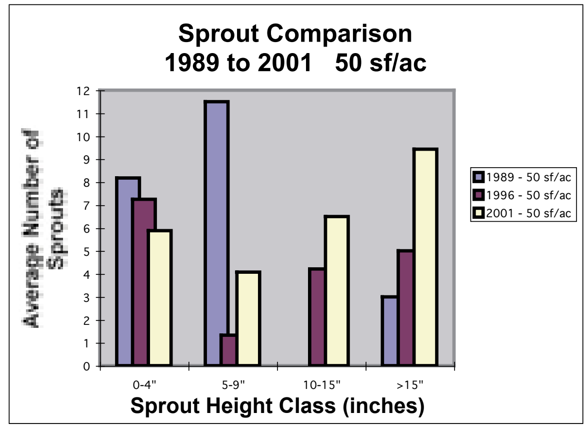


Figure 24. Sprout data for 50 sf/ac plots.

classified as sprouts would increase.

In the 100 sf/ac plots, there was a large decrease in the number of mounds from 1996 to 2001 (Figure 21), however, it is not clear that this decrease resulted in a corresponding increase in sprouts (Figure 23). In the 50 sf/ac plots, a closer correlation can be seen as three of the four sprout height classes showed an increase (Figure 24) likely due to the decrease in the number of mounds (Figure 22).

An interesting pattern can be seen in the sprout data for both treatment plots. In the 0-4 inch height class, both the heavily thinned and lightly thinned plots showed a similar decrease in the average number of sprouts. In the 50 sf/ac plots, this decrease over time in the 0-4 inch height class can be shown as a corresponding increase in the remaining three sprout height classes. One would expect this type of pattern as clumps gave way to sprouts that grew taller until they reached such size to be considered ingrowth.

This pattern is less distinct in the 100 sf/ac plots. The near disappearance of clumps in 2001 in the 100 sf/ac plots is not shown as an immediate gain in the average number of sprouts.

Overall, the heavily thinned plots showed a wider array of clumps and sprouts.

<u>Natural Regeneration</u>

In 1996, Site 5 was the first to show signs of natural regeneration. The more heavily thinned 50 sf/ac plot (5-1) had 31 natural sprouts averaging 8.4 inches, while plot 5-3 had 2 natural sprouts averaging 11.0 inches. In 2001, the data showed that plot 5-1 had 32 natural sprouts averaging 5.3 inches, and 5-3 had 7 natural sprouts averaging 4.0 inches. The decrease in average height of the sprouts in Site 5 could be attributed to the movement of some of these natural sprouts to ingrowth with replacement by younger, natural sprouts. In addition to Site 5, Sites 4 and 10 in 2001 also contained natural sprouts as can be seen in Table 12.

Table 12. Natural Sprouts

100 sf/ac plots Site/Plot	1996 Av. Height	1996 Count	2001 Av. Height	2001 Count
4 - 1	0.0	0	14.7	10
5 - 3	11.0	2	4.0	7
10 - 3	0.0	0	6.2	10

50 sf/ac plots Site/Plot	1996 Av. Height	1996 Count	2001 Av. Height	2001 Count
4 - 2	0.0	0	27.3	8
5 - 1	8.4	31	5.3	32
10 - 1	0.0	0	6.5	1

The Forage Layer in the Thinned Plots

Part of this study was to examine how the biomass of forage was altered following thinning of the overstory and how that biomass then changes over time. Forage samples were collected using a 2 foot square frame (4 square feet) placed on an area that was subjectively determined to represent the average of all forage species within the plot. All forage species were recorded, and above ground grasses and forbs (which an animal would eat) were clipped to the ground. Samples were oven dried, weighed, and expressed in lbs/acre (Stechman 1986).

In the 2001 inventory *Carduus pycnocephalus*, *Bromus diandrus*, and *Avena* spp. were found to some extent on almost all of the sites. It was estimated that they occupied 50 percent or more of the grass layer.

It was interesting to note that the drastic change in species between the 1996 and 2001 inventories, was similar to the change between the 1989 and 1996 inventories. Every plot in the study had a major change in species composition of the grasses and forbs. The high degree of variability in only a few years is astounding. These findings allow for no valid projection of which species may develop following a thinning treatment.

The only species common to the three inventories is wild oats (*Avena fatua*). This species was found in 24 of the 27 plots in the 1989 inventory, in 5 of the 27 plots in the 1996, and in 10 of the 27 plots in the 2001 inventory. The most common species found in 2001, and the number of plots in which each species was observed, is presented in Table 13.

Table 13. Species common in the study sites for the 2001 inventory.

Common Name	Scientific Name	Number of Plots (n=27)
Creeping snowberry	*Symphoricarpos mollis*	10
Ripgut brome	*Bromus diandrus*	10
Wild pea	*Vicia* spp.	11
Wild oat	*Avena fatua*	10

As in the 1989 and 1996 inventories, we found that the species in the forage layer did not vary by treatment as much as by site. The same forage species were usually found in all three plots of the same site, though in different proportions.

For these reasons, treatment averages were not compared. Instead, Figure 25 is provided to show the influence of both site and treatment on individual plots. Note that 3 of the 9 sites show the "textbook" pattern where the 50 sf/ac plots produce more forage biomass than the 100 sf/ac plots, which, in turn, produce more than the control plots.

Clawson, McDougald, and Duncan (1982), suggest that 700 lbs/acre is considered the minimum or lower threshold level of residual dry matter on gentle to steep slopes in the Central Coast Foothills. Using this value, Figure 25 shows that only two sites exceed this level in 2001.

Total forage biomass averages were compared for the 1989, 1996, and 2001 measurement periods. Figure 26 shows the relationship of forage biomass growth over the past 17 years. Only the heavily thinned plots (50 sf/ac) exhibit the pattern you would expect after thinning. These plots showed an increase of forage after thinning in 1984 followed by a steady decrease.

One may expect a corresponding increase in percent crown closure over the same time period, however, this is not the case. In Figure 27, you can see that percent crown

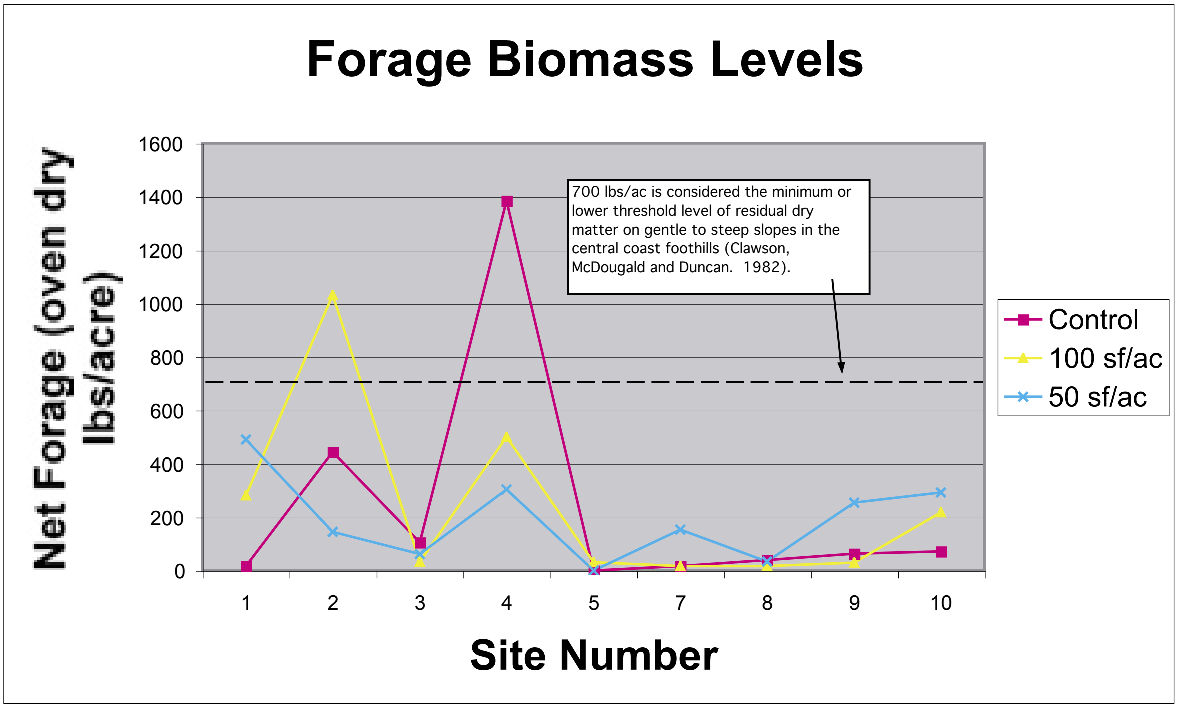


Figure 25. 2001 forage biomass for the coast live oak thinning plots. Note that site 6 was dropped from the study.

closure in the 50 sf/ac plots has only slightly decreased partly because no ingrowth has put on crown area.

Also, there is a significant amount of variability from inventory to inventory that

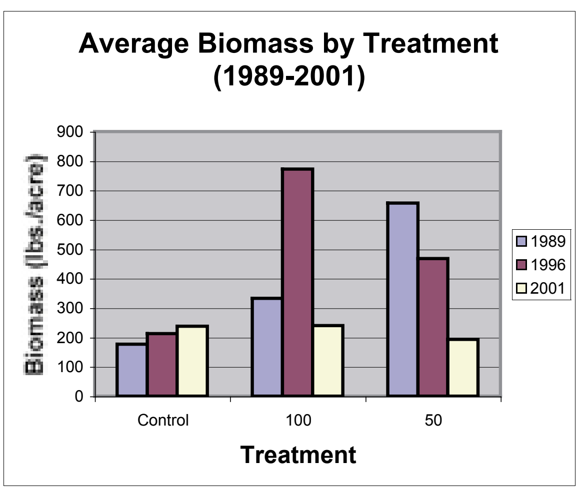


Figure 26. Change in biomass over the seventeen-year period.

does not appear related to thinning. For example, no single plot met the 700 lb/ac criteria in any 2 of the 3 inventories.

This study was designed using basal area as a method to manipulate the stand, primarily because of the ease of application and measurement. However the relationship between a stand's basal area and its percent crown cover is not well defined. The average

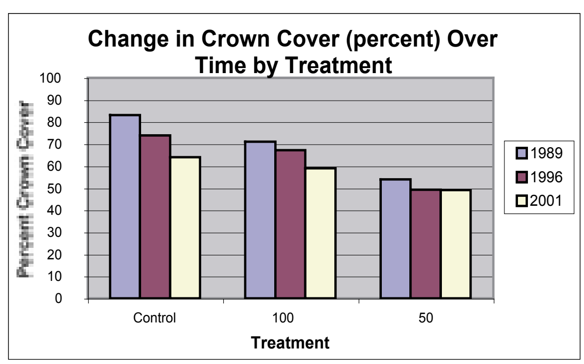


Figure 27. Change in crown cover over the seventeen-year period.

crown closure in percent for the treatments is shown in Figure 27.

Even though a large volume of wood was removed from the 50 sf/ac plots the remaining trees currently occupy 49% of the crown space. Clearly a further reduction is needed before significant increases in forage will be obtained; perhaps a crown cover in the 35-40% range would yield levels of forage in excess of 700 lbs/acre.

The data in these tables and figures demonstrates the lack of correlation between thinning and forage. The decreasing quantities of forage biomass in the heavily thinned plots could be more of a function of weather or time of summer measured, than a decrease in crown closure. This is especially true since sites 2 and 4 had a dramatic increase in biomass since 1996, and these sites are strongly influencing the average amount of biomass shown in Figure 26.

It is our conclusion that the level of forage production measured at the end of seventeen years is not adequate to allow normal grazing because there would not be enough residual dry matter for the next year on a consistent basis. However, in the interpretation of the forage data it is important to consider the relationship between a stand's basal area and its percent crown cover as it relates to forage.

Woody Shrubs

Understory density for each site and plot was estimated by percent during each of the four remeasurement periods. The treated plots all showed the expected increase in density of woody shrubs for the first three remeasurement periods. As shown in Figure 28, in 2001 the average density of the woody shrubs in the lightly thinned plots decreased yet the density in the heavily thinned plots continued to increase. These results are likely related to the amount of crown space that the canopy occupies in the overstory. The more open, heavily thinned plots continued, after 17 years, to allow sufficient light to pass through the canopy promoting the continued growth of the woody shrubs. As the overstory closed in more quickly in the lightly thinned plots, after 17 years, the density of the woody shrubs showed a decline.

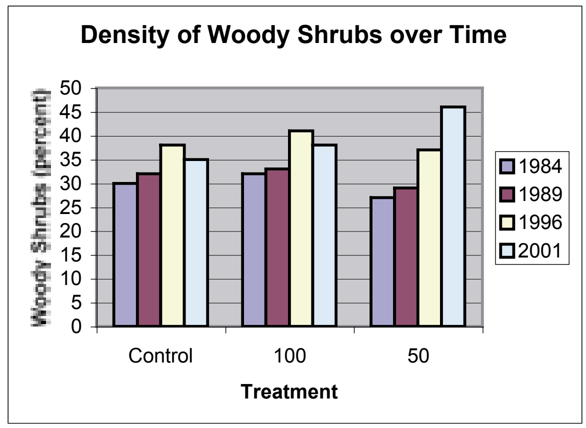


Figure 28. Change in shrub density from 1984 to 2001.

Although not expected in the control plots, the density of the woody shrubs increased over the first twelve years then decreased in the 2001 remeasurement. Although this was not expected in the control plots, the changes in density of the woody shrubs follow the pattern of change shown in the percent crown closure of the overstory. Crown closure percent decreased in the control plots over the 17 year period likely due to natural causes such as fire, disease, senescence, and competition. Decreasing crown closure in the control plots allowed more resources to pass through to the understory to be utilized by the woody shrubs. The decrease in the 2001 remeasurement could be attributed to an equilibrium being attained between decreasing crown closure and increasing woody shrub densities, similar to what is seen in the lightly thinned plots. In fact, the 2001 crown closure percents for the control and lightly thinned plots were 64% and 59%, respectively. This is compared to the relatively more open canopy of the heavily thinned plots, which measured 49% in 2001.

GROWTH AND YIELD CONCLUSIONS AND RECOMMENDATIONS

The first seventeen years of growth information has been collected and analyzed for the coast live oak thinning study. The interpretation of this data is discussed below in the form of conclusions and recommendations.

1. Two major forest fires occurred during the seventeen-year interval that affected the study. Our data shows that the more dense, unthinned plots sustained greater damage from fire than did the treatment plots. Proper care and management of the woodland forest can reduce losses from fire and, in general, protect the value of the resource.

By 2001, the control plots, study wide, had an average mortality of 92.8 trees/acre. This compares to 13.9 trees/acre lost in lightly thinned plots (100 sf/ac), and 5.6 trees/acre lost in the heavily thinned plots (50 sf/ac).

This was more dramatically shown in Site 1, which was heavily burned as a result of two fires during the 17 year period. The control plot lost 82.5% of its trees compared to the treatment plots which lost an average of 25.5%.

Because of the mortality caused by fire and snow, these data show not only the positive results of thinning but also the loss of growth that can occur when stands are not properly managed.

2. Many of the stands in the thinning study are thought to be near rotation age. Could they benefit from a thinning at this age?

The answer to this question is "yes." The benefits were already apparent in the five-year inventory, and that trend has strengthened after seventeen years of regrowth.

Both basal area and total volume growth percentages were significantly greater in the thinned plots than the control plots. Average basal area per acre growth rates for the seventeen-year interval were 22% for treatment plots and 1% for control plots. Average total volume growth rates per acre for the treatment plots is 51%, compared to 19% for control plots. In general, wood volume growth was approximately 2.5 times greater in the treated plots compared to the control plot, and sawlog volume increased by 12%.

Clearly coast live oak , even at this age, respond in a positive manner to thinning.

3. Prior to thinning, all 30 plots in the study were measured and their growth rates were found to exceed the Forest Service definition for Productive Land (20 cf/ac/year). In fact they averaged about 70 cf/ac/year.

As of 2001, the only treatment that is increaing in MAI (cf/ac/yr) is the heavily thinned plots. This is rather impressive given that tree MAI is expected to slow considerably in later years.

An independent site, growth and yield study conducted on 25 plots in San Luis Obispo and Monterey counties in 1985 showed similar results. In that study, coast live oak plots averaged about 60 cf/ac/year. In both studies the researchers sampled only moderately dense to dense stands, the typical growth pattern for coast live oak.

This information is significant as it relates to the potential for silvicultural practices to positively influence production of middle aged stands, which is important for the management of forests for commercial products.

4. As predicted in the last inventory report, ingrowth is now being seen. It should be noted that it has taken 17 years for ingrowth to appear. Stumps were not protected in this study, however, we recommend that protection measures be taken in similar thinnings in order accelerate ingrowth.

5. Cut stumps on thinned plots were evaluated for their ability to produce sprouts. In 1989 about 55% of the stumps were observed to have formed a clump. In 1996 (twelve years), about 17% of the stumps still showed the clump form, while in 2001 approximately 3% remained. This trend is expected because over time clumps would give way to sprouts or possibly die.

There has been a general declining trend in the number of sprouts during the three inventory periods. It is our observation that this occurred for two reasons. One is that some sprouts have escaped to the tree stage, while others have been browsed and subsequently died.

This means that regeneration by coppice methods is not going to occur rapidly following thinning by itself. Some method of protection, such as screens or piling brush on the stump, is necessary to encourage rapid regeneration.

6. The possibility of increased production of forage following thinning was less promising. First, a tremendous variation by site was observed. This greatly confounds the effects of thinning and interpretations of treatment effects is not advised. In addition, only two plots produced enough forage to exceed the recommended minimum threshold of residual dry matter (no change since the 1996 inventory).

The lack of greater quantities of forage production is due to the relatively high crown cover that was left after thinning. Even the most heavily thinned plots (50 sf/ac) averaged nearly 50% crown cover (49%), while the 100 sf/ac plots averaged 59%. If forage production is a major objective of the landowner, further reduction in crown cover is necessary before enough light will be available to produce usable levels of forage.

7. The condition of the soil was evaluated in each inventory. No type or amount of erosion was observed on any plot regardless of the land slope. Apparently, the crown and root density left after thinning was sufficient to protect the site.

8. An economic valuation of the response to thinning, in 1996, showed that the expected rate of return from similar management would yield a sustainable $30/acre annually. When combined with grazing (which is expected to yield between $30-$40/acre per year), and managed wildlife production, the landowner is able to achieve a competitive 6% return on a land investment cost of $450 per acre.

Therefore, a landowner can conduct an economically viable thinning operation and accomplish several objectives, including land stewardship, at the same time. The results of our analysis show that a forest or woodland will continue to grow and increase in value well into the second decade following thinning.

The temptation to wholesale harvest all trees (clearcut) can be resisted by knowing that some income can be available immediately following thinning and that the remaining trees are also adding value at a more rapid rate than before. Thus, the landowner has not only gained some immediate income and enhanced his or her woodlands responsibly, but by retaining the forest cover on the soil has also kept his or her options open to future decisions. The authors felt that this conclusion was not changed by the data measured in 2001 and remains valid.

9. For the 2001 economics analysis portion of the study, a different facet of economics was evaluated. We looked at the costs of management in the wildland urban interface in relation to fire behavior and the costs associated with fire suppression effots.

The wildland-urban interface lands in California, of which the oak woodlands are a significant part, are at high risk to loss from fire associated with development pressure. The risk arises from the contradiction that natural fire can neither be permitted nor eliminated. This contradiction produces unnaturally intense, ecosystem-destructive fires that actually increase risks to life and property. Changing this condition requires new policies that encourage investments in forest management to allow people to live and work with fire, not against it.

Currently, state and federal policies and programs are available to assist landowners in mitigating the costs of pre-fire planning and vegetation management. Various cost-share programs are available to landowners – Forestry Improvement Program (FIP), Stewardship Incentive Program (SIP), and the California's Forestry Improvement Program (CFIP) – but the funds have been small and declining. There is a clear need for a public incentive program for management of these interface oak woodlands in order to promote investment to fire safe these landscapes.

10. More information is needed to help answer the questions of how intense a thinning prescription needs to be in order to be sustainable (i.e. promote regeneration of the forest) while still accomplishing the fire-safing effects sought from the thinning. We recommend that controlled fire experiments be conducted on various mechanically thinned plots to determine the least intense (and thus lowest-cost) thinning level that will accomplish both of these important goals. In addition, further research should be done in different oak woodland species types to find the best prescription to meet these needs.

11. Lastly, research should be undertaken to ascertain the effects of thinning prescriptions, which eliminate the fuel ladder, on wildlife species. The near-complete removal of any one layer of vegetation in a landscape could have indirect effects on wildlife, most likely avian species. Information about these possible effects should be gathered before single-focus resource management actions are implemented on a large scale. This type of information would greatly assist resource managers with their necessary environmental evaluations under the California Environmental Quality Act (CEQA) and would help facilitate an ecosystem management approach to fire-safing the landscape.

12. Our recommendation is that the growth and yield portion of the study be concluded at the 25 year anniversary and that the sudden oak death portion of the study be reviewed for continuation.

SUDDEN OAK DEATH

Introduction and Background

A new aspect added to the study in 2001 is the establishment of Sudden Oak Death (SOD) study plots. SOD is a disease that is caused by the pathogen *Phytophthora ramorum*. Although it is called a fungus by most, the *Phytophthora* organism is technically classified as a "killer brown algae." Many different species of *Phytophthora* exist (approximately 60 worldwide) and have been linked to diseases such as Port Orford cedar root disease in Northern California and Southern Oregon and jarrah dieback in Australia. SOD was first detected in tanoak trees in Mill Valley, California (Marin County) in 1995, however, the cause of the disease at that time was unknown. In June of 2000 a new species of the *Phytophthora* pathogen, suspected to be the cause of SOD, was isolated from dying trees in California. This newly discovered *Phytophthora* species was first isolated in Germany and The Netherlands in 1993 in ornamental rhododendrons. However, it was not until January of 2001 that scientists discovered that the *Phytophthora* isolated in Europe and in California was the same. It was then officially given the name *Phytophthora ramorum* (http://www.cemarin.ucdavis.edu/history).

In an attempt to understand Sudden Oak Death, the 60 known *Phytophthora* species are being studied. For example, *Phytophthora lateralis*, the cause of Port Orford root disease, is believed to be the closest relative to the genus and has become a primary source of information. Scientists are studying both the similarities in the two pathogens as well as the characteristics of the diseases caused by these pathogens. Comparisons have also been made with jarrah dieback and its pathogen *Phytophthora cinnamomi*. Of particular significance is the presence of thick walled propagules in these *Phytophthora*, suggesting the ability to survive for long periods of time in wood and soil during periods of unfavorable conditions for growth and reproduction. It is believed that the primary mode of spread is through soil, water, and the movement of infected plant material. In addition, spread through airborne spores has also been shown. It is most active and therefore most transferable during the wet seasons of the year. The most heavily impacted areas have been in recreation sites, suggesting that human activities may also be responsible for the spread.

In addition to the pathogen being more active in the wet season, soil, which is considered a major vehicle of spread, is more easily transported during this time of year. People may be unintentionally spreading the pathogen on the soles of their shoes as well as vehicle and bike tires. [1]

Distribution of Disease

P. ramorum has been confimred in 13 counties in California and Curry County in southern Oregon. The infected counties as of spring 2004 in California include: Alameda, Lake, Marin, Mendocino, Monterey, Napa, San Mateo, Santa Clara, Santa Cruz, Solano, Sonoma, Humboldt, and Contra Costa. The most northern confirmed identification in California is in the town of Redway in Humboldt County. The most southern confirmation is at Plasket Creek, Monterey County, only 10 miles from the San Luis Obispo County line. The confirmed site farthest inland is in Solano County (see Oak Mapper; www.suddenoakdeath.org).

1 A full list of current recommendations on the prevention of spread can be found on the California Oak Mortality Task Force web page at www.suddenoakdeath.org. In addition, the California oak Mortality Task Force Biomass Utilization Committee has developed a document called Sudden Oak Death Best Management Practices in Zone of Infestation Regulated Areas. The document lists mitigation measures to minimize the movement of host material and soil from infested areas and guidelines for when these mitigation measures are warranted.

Hosts and Symptoms

The list, as of Spring 2004, of regulated hosts and associated plant species is shown in Table 14. There are basically two categories of hosts for the *P. ramorum* pathogen, which include bark canker hosts and foliar hosts. The bark canker host becomes infected on the trunk, while foliar hosts become infected on the leaves. The hosts shown in bold font were present in our study plots.

Phytophthora ramorum infections in bark canker hosts often result in mortality but only occasionally cause mortality in foliar hosts. The three true oaks (coast live, black, and Shreve's) as well as tanoak exhibit cankers or lesions on the lower six feet of the trunk. These cankers or lesions are characterized by dark burgundy to brown exudates or bleeding on the exterior of the bark. A distinctive symptom of infection is the presence of dead tissue (dark brown to black) surrounded by black zone lines directly beneath the exudates under the bark layer. In the later stages of infection, other opportunistic organisms may be present as a result of the compromised condition of the tree. These organisms include the sapwood decay fungus *Hypoxyln thouarsianum* as well as ambrosia and bark beetles. The sapwood decay fungus produces dark green to charcoal black half dome shaped fruiting bodies on the outer bark of the tree.

Table 14. Regulated hosts and associated plant species of P. ramorum.

Regulated Hosts

Scientific Name	**Common Name**
Acer macrophyllum	Bigleaf maple
Aesculus californica	**California buckeye**
Arbutus menziesii	**Madrone**
Arctostaphylos manzanita	Manzanita
Camellia japonica	Camellia
Heteromeles arbutifolia	**Toyon**
Lithocarpus densiflora	**Tanoak**
Lonicera hispidula	**California Honeysuckle**
Pieris formosa	Andromeda
Pseudotsuga menziesii v.menziesii	Douglas fir
Quercus agrifolia	**Coast live oak**
Quercus chrysolepis	Canyon live oak
Quercus kelloggii	California black oak
Quercus parvula v. shrevei	Shreve oak
Rhamnus californica	**California coffeeberry**
Rhododendron spp	Rhododendron
Rosa gymnocarpa	Wood rose
Sequoia sempervirens	Coast redwood
Trientalis latifolia	Western starflower
Umbellularia californica	**California bay laurel, Oregon myrtle,**
Vaccinium ovatum	Huckleberry
Viburnum x bodnantense	Bodnant Viburnum
Viburnum tinus	Laurustinus
Camellia sasanqua	Christmas Camellia
Pieris formosa x japonica	Andromeda spp.
Pieris floribunda x japonica	Mountain Pieris spp.
Pieris japonica	Japanese Pieris
Viburnum plicatum var. tomentosum	Shoshone
Hamamelis virginiana	American witch hazel

Associated Plant Species

Scientific Name	**Common Name**
Abies Grandis	Grand fir
Aesculus hippocastanum [1]	Horse chestnut
Arbutus unedo	Strawberry tree
Camellia sasanqua	Camellia
Castanea sativa [1]	Sweet chestnut
*Corylus cornuta***	California hazelnut
Fagus sylvatica [1]	Beech
*Kalmia latifolia** **	Mountain laurel
*Rhamnus purshiana***	Cascara
Pieris formosa s japonica	Forest Flame Andromeda
Pieris floribunda x japonica	Brouwer's Beauty Andromeda
Pieris japonica	Varigated and Flaming Silver Andromeda
*Pittosporum undulatum***	Victorian box
Quercus cerris [1]	Turkey oak
Quercus falcata [2]	Northern red oak
Quercus ilex [1]	Holm oak
Quercus rubra [2]	Southern red oak
Syringa sp.	Lilac
Toxicodendron diversiloba	**Poison oak**
Rubus spectabilis	Salmonberry
Taxus baccata	European Yew
Vaccinium vitis-idaea	Lingonberry
Viburnum plicatum tomentosum	Mariesii - Doublefile Viburnum

1. Species found to be infected in Cornwall, England
2. Two additional trees in Europe known to be infected - Quercus rubra in the Netherlands, and Quercus falcata in Sussex, England.

* Mountain laurel is known to be susceptible in Europe but has not yet been observed as naturally infected in the United States.

** California hazelnut, Cascara, Pierus, poison oak and Victorian box are plants associated with P. ramorum. To date, however, these plants have not been confirmed as hosts.

The presence of beetles can be detected by reddish brown or tan frass as a result of their boring into the tree. In addition, the actual appearance of beetles or their galleries may be a sign that the tree is infected. Once the tree is dead, the leaves will turn brown uniformly, but stay attached to the tree.

Foliar hosts may display a variety of symptoms depending on the host species. Some symptoms include leaf spots, stem cankers, twig die back, leaf wilting, twig cankers, and branch die back. Although most foliar hosts do not seem to be suffering mortality from the disease, they are critical as a pathway for spread in regions where no other hosts are present. Researchers have observed that the pathogen can reproduce rapidly on the leaf surface of some foliar hosts. This allows for the rapid build up of *P. ramorum* spores and further facilitates the spread of the pathogen.

It has also been shown that the pathogen will colonize leaves of foliar hosts and tanoaks first. Therefore, suspicious spots and blotches on leaves of two or more hosts is often an indication that the disease is present in that area, but has not yet infected or caused cankers on the oaks or tanoaks.

Because of the diversity and similarities of the signs and symptoms of this disease to other diseases, confirmation in the field is impossible. Samples are taken from suspect trees and then sent to a professional lab to test whether the tree is positive for the pathogen or not.

<u>Significance to Study</u>

Sudden oak death has been spreading throughout the central coast of California since 1995 and has killed large numbers of coast live oak (*Quercus agrifolia*), black oak (*Quercus kelloggii*) and tanoak (*Lithocarpus densiflorus*). The primary reason for incorporating this disease into the study is to monitor spread through coast live oak stands and to aid in reporting any newly infected counties or species.

There are several advantages of expanding the Growth and Yield study to include an investigation of SOD.

This study is the only long-term study of its kind in California. In addition, five of the 10 study sites are in a county bordering the zone of infestation offering us an opportunity to monitor sites found both within and outside the zone.

An advantage of thinning is to create healthier stands. Traditionally, from a silvicultural perspective, managed stands are considered more healthy. One of the objectives of this study was to create both healthy plots (treatments) and less healthy plots (control). This was done by setting some plots up as control (no treatment) and others as managed (thinned) plots. If SOD moves into any of the sites, the question is, would the treatment plots (more healthy) be more resistant than the control plots (less healthy plots)? The hypothesis for this portion of our study is that treatment and control plots are equally resistant to Sudden Oak Death. This is an ideal opportunity to test whether the likelihood of infection and/or rate of mortality is related to background health status.

This disease has the potential to greatly affect mortality rates as well as overall health and existence of coast live oak stands throughout the central coast of California. Because this study evaluates the health, vigor, and growth rates of coast live oak stands, it was essential that the effects of this disease be incorporated into the study. Should SOD move into any of the ten locations in this study, an opportunity to study the correlation between vegetation density, infection rate, infection intensity, and mortality levels will occur. Information of this type could prove very useful for developing silvicultural recommendations to minimize spread and mortality associated with this disease. In addition, this study currently provides 17 years of information on the baseline condition of coast live oak stands prior to infection and could potentially provide the ability to evaluate the effects of thinning on the occurrence and spread of the pathogen.

Sudden Oak Death Objectives

1. Evaluate each tree in the expanded growth and yield plots for the presence/absence of SOD and other pests and diseases.

2. Conduct a reconnaisance of 3-5 acres in each study area to determine if any obvious occurences of SOD were present within the immediate area.

3. If *P. ramorum* is confirmed, analyze whether a correlation between SOD and other pest and diseases exists. Analysis would also convey the level of infection at each site and summarize the level of infection, study wide, by thinning prescription.

4. A baseline level of mortality dating back to 1984 will be measured excluding SOD factors. If SOD is present, we will estimate the rate of spread by stocking rate, tree size, and tree growth rate. Sudden oak death progression in thinned vs unthinned stands (management) will be quantified.

Methodology

It was thought that the one-fifth acre growth and yield plots were too small to adequately capture SOD occurrence, so all plots were expanded to 3/5 of an acre. The added 2/5 of an acre was centered around the original 1/5 of an acre plots (some exceptions to this were made when the plots had to be moved to avoid overlap or development). The outer 2/5 of an acre is designated for SOD observations only while the inner 1/5 of an acre is used for the growth and yield study as well as SOD observations. The 3/5 of an acre plots are square in shape with 161.7 feet on each side. Figure 29 shows the conceptual layout for each of the study plots. In order to help facilitate recording of tree location in the outer SOD plots, they were divided into four sections. The north section of the plot is section one and the other three are designated as 2, 3, and 4, moving clockwise around the plot.

We first located the center of the fifth-acre plot. From the center we measured a horizontal distance of 114.3 feet at 45-degree angle offsets from cardinal directions. We repeated this step for all four corners and marked each with a wood stake labeling it as SOD plot number and corner (i.e., SOD plot 1-3 SW corner). After marking each corner we flagged the outer boundaries of the plot using a hand compass in order to better designate which trees are in the plot (flagging was removed after measuring). In cases where plots overlapped or included developed or developing areas, the plot was shifted in a direction that avoided these conditions. In most cases we simply shifted the outer SOD plot 34.2 feet in one of the cardinal directions.

Once the outer SOD plot was established, every tree in the plot was tagged with

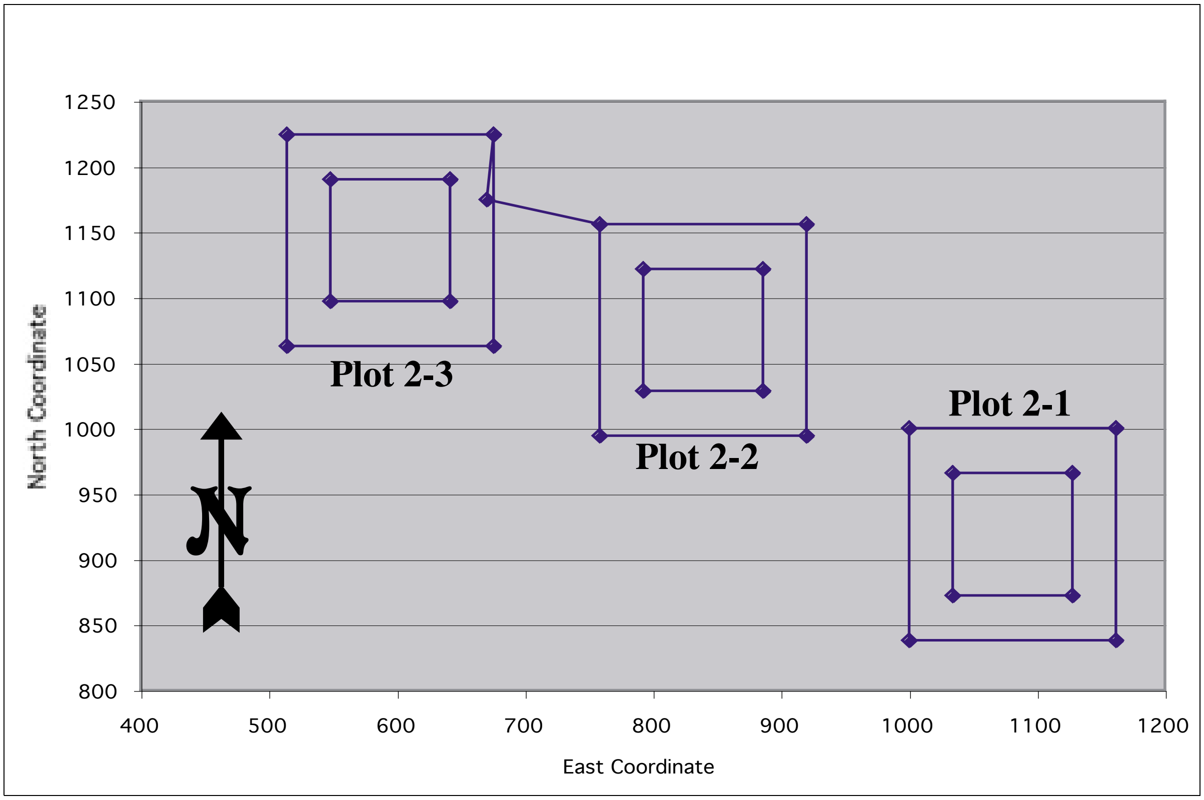


Figure 29. Field layout of Site 2, Elkhorn Slough Estaurine in Monterey county. The inside plots are for growth measurments, the entire plot was surveyed for sudden oak death.

a number using oval shaped tags in order to distinguish them from the fifth-acre plot trees. In addition, tree number, DBH, section, damage and disease, and signs or symptoms of SOD were recorded for each tree. Because the primary goal of the outer SOD plots is to monitor the sites for SOD, heights were not measured, and DBH was measured using a Biltmore stick to serve as a reference for tree identification. The same damage and disease codes used for fifth-acre plots were used for SOD plots. Lastly, a column to indicate suspicion of SOD was added.

If trees exhibited possible signs or symptoms of SOD, they were further investigated. In order to examine oak trees that exhibited bleeding, a hatchet, sterilized with Lysol spray, was used to cut beneath the outer layer of bark to look for dead tissue and zone lines. If the tree did not exhibit zone lines and had no other distinctive signs or symptoms and no signs or symptoms were found on surrounding trees, it was assumed that the bleeding was from other causes. Further, all known foliar hosts were examined for signs or symptoms of the disease at each site.

Any trees that exhibited symptoms that could indicate SOD were recorded and then reported to Dr. Walter Mark, a plant pathologist at Cal Poly State University, San Luis Obispo, who is assisting in the study. Because proper sample procurement is essential to the laboratory analysis for SOD, samples from suspect trees were collected by personnel specifically trained in SOD sampling protcols.

Results of SOD Investigation

The summer 2003 measurements completed three consecutive years of SOD investigation on and near the coast live oak growth and yield plots. Field crews were trained in SOD recognition and sampling techniques. They found numerous trees with symptoms of SOD, which were further investigated.

Some of these investigations led to collection of tissue samples which were analyzed by the UC Davis laboratory. Table 15 shows the results of samples taken over the past three years.

Table 15. Results of SOD laboratory analysis.

Coast Live Oak Trees Tested for SOD

Year	Site/Plot No.	Tree No.	Results
2001	3-1	398	Negative
2001	3-1	404	Negative
2001	3-3	936	Negative
2001	3-3	29	Negative
2001	3-3	435	Negative
2001	3-3	597	Negative
2001	3-3	983	Negative

Year	Site/Plot No.	Tree No.	Results
2002	4-3	734	Negative
2002	3-3	433	Negative
2002	3-3	450	Negative
2002	near site 2*	n/a	Negative

*Tree in Long Valley on Elkhorn Slough Reserve checked for SOD at request of Elkhorn Slough personnel.

Year	Site/Plot No.	Tree No.	Results
2003	3-1	712	Negative
2003	3-2	241	Negative
2003	3-2	240	Negative
2003	3-3	900	Negative
2003	3-3	917	Negative
2003	3-3	927	Negative
2003	3-3	49	Negative
2003	3-3	420	Negative

Throughout our thirty study plots in 2001, seven trees were recorded as having SOD-like symptoms. All seven trees were at Site 3 located in Adelaida, California.

Samples were taken from all seven trees and the subsequent lab analysis concluded that the trees were infected with the *Phytophthora cinnamomi* pathogen but did not have sudden oak death. Fortunately, no foliar hosts were found to exhibit signs or symptoms of SOD.

In 2002, a new site, Site 4, showed symptoms of SOD. One tree from Site 4-3 was sampled and found to be negative. Also, two trees from Site 3 were sampled that were not sampled in 2001. Those trees were also found to be negative for *P. ramorum*. During the reconnaisance of the area at Site 2, one tree was observed as having signs associated with SOD. It was also tested and found to be negative.

Eight trees were tested in 2003, all from Site 3. All trees were found negative for *Phythopthora ramorum*. We are especially interested in continuing observations at Site 3 because it is located in San Luis Obispo county which is a county bordering the southern end of the zone of infestation. Further, due to the degree of non-SOD symptoms shown at Site 3, we are interested to see if this is a precursor to the arrival of SOD.

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