

Whiskey Springs Long-Term Coast Redwood Density Management; Final Growth, Sprout, and Yield Results

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Abstract

Multi-decadal studies of commercial and precommercial thinning in redwood stands are rare and consequently of value. The Whiskey Springs study at Jackson Demonstration State Forest has a data set spanning 35 years. In addition to growth and yield response to commercial thinning, the results provide important information for evaluating regeneration and alternative silviculture treatments.

In 1970, the original treatment thinned a 40 year-old redwood forest from below to densities representing 25, 50, and 75 percent of the initial basal area (approximately 400 ft²/ac). Three 0.2-ac plot replicates within each of the four density levels were assigned in a randomized design. In the 35 years after thinning, the basal area of the 25, 50, 75 and 100 (control) percent retention areas increased by 168, 232, 226 and 210 ft²/ac of basal area respectively. There was some indication that mean annual increment (ft³/ac) had culminated at age 70 years for some treatments.

Redwood sprouts and other conifer seedlings were abundant in the 25 and 50 percent retention areas. Precommercial thinning subplots were established within these two treatments in 1986, reducing the understory to 200, 300, and 400 sprouts/ac. The understory diameters ranged from 2 to 6 inches at DBH for the 25 percent retention 35 years after the commercial thinning.

Key words: *Sequoia sempervirens*, coast redwood, commercial thinning, precommercial thinning, regeneration, sprouting

Introduction

This report provides the final measurements for what began as the Whiskey Springs Redwood Commercial Thinning Study. It was established by the USDA Forest Service and the California Department of Forestry and Fire Protection staff in 1970 on Jackson Demonstration State Forest (JDSF) in 1970 near Fort Bragg, California. This study spans 35 years after thinning of a 40 year-old, well stocked second growth stand. The original experimental design included three sites located in the redwood region. Oliver et al. (1994) reported the first 15 years of growth (1971 to 1985) for all three sites. James Lindquist has summarized periodic remeasurement

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data at JDSF (1988, 2004). The now 75 year-old stand has literally outgrown the study design and has transitioned into an educational demonstration site.

The study was designed to test treatments to help realize the productive potential of young redwood forests. The original study plan called for a final harvest at 70 years of age based on the projected culmination of the mean annual increment on a cubic foot volume basis for a 100-year site index of 180 ft.

Vigorous coast redwood (*Sequoia sempervirens* [D. Don] Endl.) sprouting occurred after the commercial thinning. A secondary regeneration focused study was established to examine this sprouting. The understory sprouts were precommercially thinned to a range of densities. Natural regeneration and redwood sprout growth were measured periodically beneath the thinned overstory.

The objective of the experiment was to test a range of commercial thinning intensities for the purpose of comparing total yield. The experiments' growth and yield data aids in planning silvicultural prescriptions in redwood to achieve maximum board foot volume production or other attributes such as target tree size. This data provided stand structure information to help inform decision-making regarding multiple goals in redwood forest management. The sprout response provided information for transitioning from even to multi-aged stand management.

This paper will provide a focused update on the final 35 year results and explore total yield and some density attributes. This long term experiment will be discussed in more detail in a California Forestry Report under preparation.

Methods

Site

The Whiskey Springs study was located approximately 9 miles from the Pacific coast, in redwood forest. There was an east to northeast aspect and an elevation range from 600 to 900 ft. The old-growth stand was clear-cut in the late 1920s. Natural regeneration of a nearly pure stand of redwood sprouts followed. There was evidence as well as records (Caspar Lumber Co.) that the area was planted with redwood seedlings around 1929. Breast-height age of redwood ranged from 39 to 41 years in 1970. Site index ranged from 172 to 212 ft, using 100 years as the base age (Lindquist and Palley 1963). The pretreatment basal area of trees greater than 4.5 inches in diameter at breast height (DBH) was 401.3 ft² per ac. The pre treatment species composition of trees by basal area was 91.8 percent redwood, 7.6 percent other conifers (Douglas-fir, *Pseudotsuga menziesii* [Mirbel]-Franco); grand fir, *Abies grandis* [Douglas] Lindley) and the remainder tanoak (*Lithocarpus densiflorus* [Hook & Arn.] Rehder).

Design

The main study established 12, 0.4-ac treatment blocks (132 x 132 ft). Measurement plots were established in a central 0.2-ac (93.3 x 93.3 ft.) section of each block. The blocks were located so that inter-plot basal area, site index, and species composition were as uniform as possible. Four thinning treatments were assigned to 12 blocks in a randomized design (Lindquist 1988). *Figure 1* shows the layout of the main study plots.

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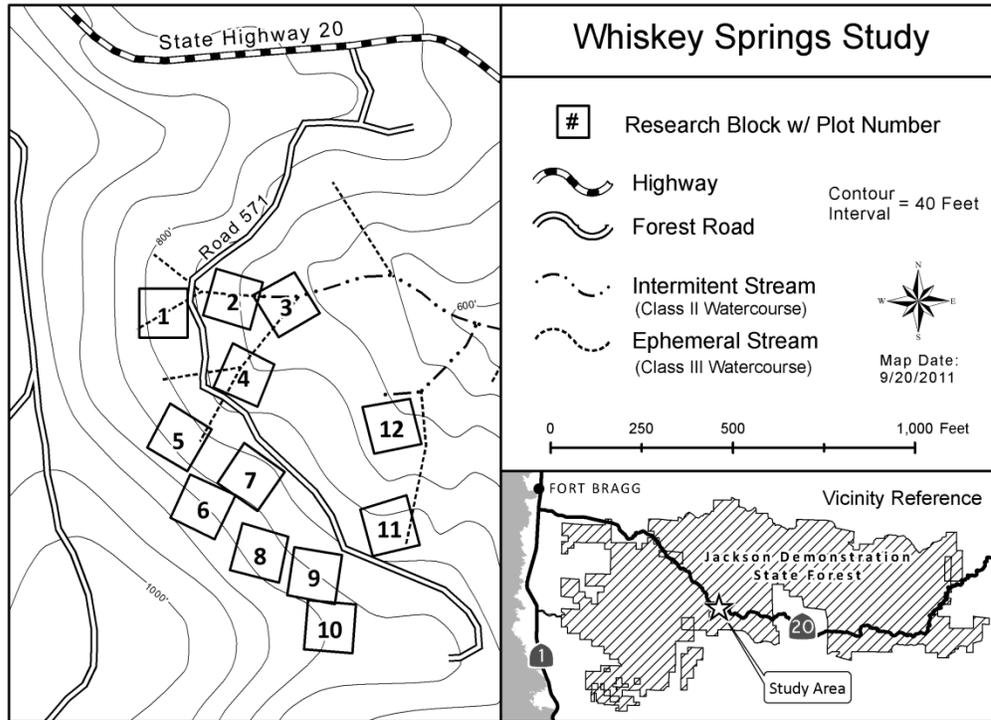


Figure 1—Plot locations at study site on topographic map and vicinity map for Whiskey Springs.

Commercial thinning in 1970 reduced basal area to approximately 100 ft²/ac (25 percent retention), 200 ft²/ac (50 percent retention), 300 ft²/ac (75 percent retention), and retained an untreated control of 400 ft²/ac.

Selection of leave trees was implemented to favor healthy dominant and codominant redwoods while leaving trees well distributed on the plot. Hardwoods and any conifers less than 4.5 inches DBH were removed. All trees were permanently tagged. After treatment in 1970 a total of seven plot measurements were conducted at approximately 5 year intervals ending in 2005.

Monitoring the effects of redwood sprouting under the four different treatment levels began in 1972. The secondary precommercial thinning study was implemented in 1986 in the 25 percent and 50 percent retention plots. The secondary study design divided treatment blocks into 1/10 ac quadrants. Each quadrant was randomly assigned to an understory regeneration stocking level of 100, 200, or 300 trees per ac and an untreated control. Leave trees for the precommercial thin were based on diameter and height, but desirable spatial distribution was also a goal (Lindquist 1988). All of the leave trees were tagged then diameters and heights were measured. Subsequent periodic measurements of the thinned understory occurred in 1991, 1999, and 2007.

Data analysis

Data was summarized for each of the seven measurement dates. It was evaluated by the statistical functions in Microsoft Excel 2007. Two way ANOVA tests were

conducted for treatment averages though the 35 year study period. For some attributes, one way ANOVA with replicates were conducted for the 2005 data.

New redwood site index equations have been developed with a base age closer to the stand age (50 vs.100 year) since the study was established. Krumland and Eng (2005) site was calculated using individual tree site values though the 35 year span for base age 50. For each plot the five best sites were averaged.

Because the stand structure became more complex as a result of the sprouting, SDI was calculated using the summation method (Tappeiner et al. 2007): $SDI = \sum (D_i / 10)^{1.0605}$. Understory diameters were adjusted to the measure date for overstory (2005).

At the beginning of the study, a limited number of trees were measured for heights. Lindquist (2004) described the method used to estimate heights for all trees. Over the 35 year study period, methods for computing volume have advanced. For this final measurement a new computation method was used. To establish height for all other trees, a nonlinear regression model (R Development Core Team, version 2.2.0, 2006) was used to develop equations based on all the measured trees (by species) for each measure year. Equations used to calculate cubic and board foot tree volumes were developed by the Redwood Yield Cooperative (Wensel et al. 1987) and locally calibrated with the JDSF fall-and-buck study (Griffen 1986). Board foot volumes were computed by the Scribner log rule using a one-foot stump height and a top diameter of 6 inches.

Because prior reports indicated between treatments cubic foot volume growth increments were similar (Lindquist 2004), and date of measurement varied during the study period; seasonal growth adjustments were made to diameters. Data from JDSF (Bawcom et al. 1961) was used to adjust diameters to a common measure date.

Results

Site quality

The treatment-wide averages for site index (Krumland and Eng 2005) were 140 ft for 25 percent retention, 133 ft for 50 percent retention, 139 ft for 75 percent retention, and 124 ft for the untreated control using 50 year base age. Small watercourses are found in about half the treatment blocks, but none in the control blocks. The average site index for plots by treatments indicated the site quality of the treatment plots were not significantly different in terms of site index ($P = 0.370$).

Mortality

During the study period, the untreated plots exhibited the highest mortality of 50 to 75 year old trees. The number of trees per ac (greater than 4.5 inches DBH) declined steadily after the first decade to 133 trees per ac or 21 percent less than the initial measurement. The 75 percent retention experienced limited mortality starting in 1985, totaling six trees per ac or about three percent of the initial measurement. No mortality was observed for overstory trees in the 25 and 50 percent retention plots.

Diameter

Heavier thinning from below (removing the smallest stems) resulted in larger average stem diameters as shown in *fig. 2*. Error bars of one standard deviation are graphed illustrating that 50 percent retention had the most variation between plots. Quadratic mean diameter was significantly different between treatments through the 35 year study period ($P < .01$).

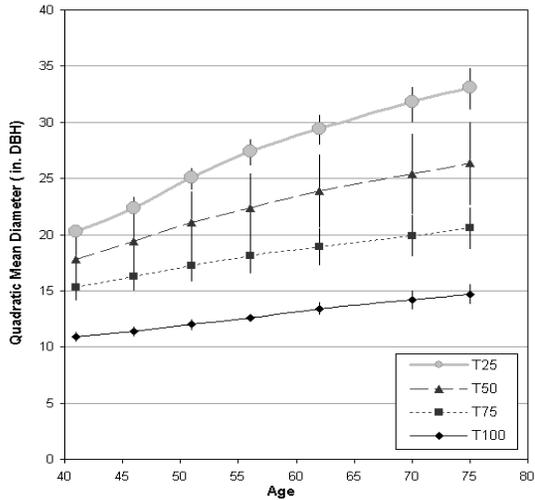


Figure 2—Mean tree diameter by treatment through time. Error bars represent one standard deviation.

Basal area

The initial treatment basal area of trees greater than 4.5 inches in diameter are depicted in *fig. 3*. The treatment's effect on total basal area per ac remained significant throughout the 35 year study period ($P < .01$).

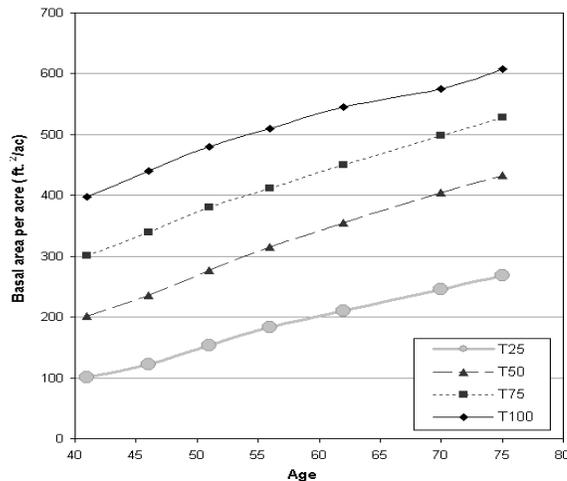


Figure 3—Basal area in square feet per ac by initial thinning density through the 35 year study period.

Volume

The untreated controls continued to have the largest cubic foot volume through the study period. For cubic foot volume there were significant differences between treatments though the 35 year study period ($P < .01$).

Mean annual increment

A biological characteristic that is of management interest is the change in growth rate by treatment through time. Mean annual increment (MAI) is the average annual growth over the life of the stand. For cubic foot volume per ac MAI; there were significant differences by treatment ($P < .01$), but not through the 35 year study period ($P = 0.0228$).

One purpose of the initial study was to determine when mean annual cubic foot growth increment peaks. For all treatments except the control, the MAI for cubic foot growth per ac reached its highest value at stand age 70 (fig. 4). Vertical error bars of one standard error help illustrate variability between plots for a single treatment. The decline in MAI was less than one percent per year, so at this point the projected culmination of mean annual increment at age 70 was suggested but not definitive.

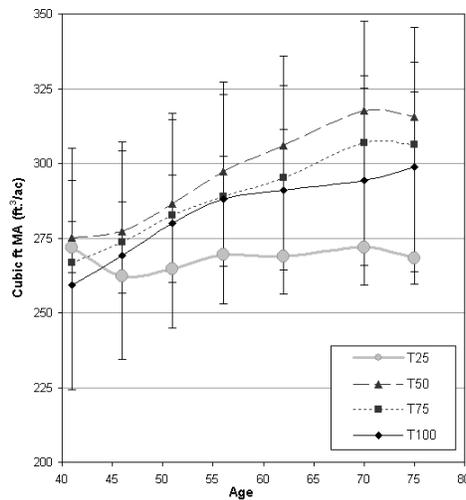


Figure 4—Mean Annual Increment of cubic foot volume per year by thinning retention treatment. Vertical error bars indicate variability of data.

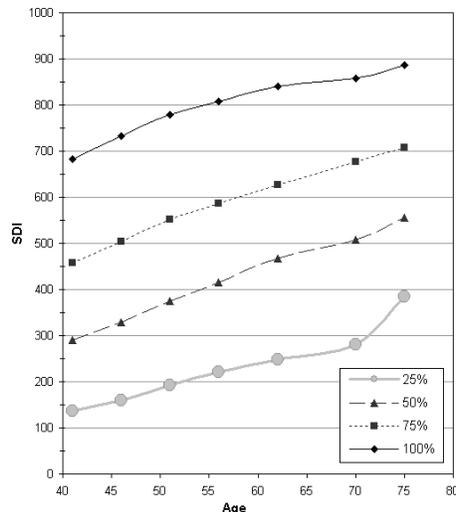


Figure 5—Stand Density Index (SDI) by treatment through time. The 25 percent and 50 percent retention at age 75 includes regeneration.

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In contrast with the MAI for cubic foot volume, the board foot volume MAI for the final measure interval continued to increase for all treatments over 35 years, but the increases were smaller than the standard errors between plots. The final MAI in board feet volume was 1,467 for 25 percent retention, 1,694 for 50 percent retention, 1,704 for 75 percent retention and 1,528 for the unthinned control. For board foot volume MAI there were significant differences for both through the study period and by treatment ($P < .01$).

Total yield

To address the original management question of effects of different commercial thinning intensities on total yield, both the commercial thinning yield at year 40 and the theoretical final harvest yield at year 75 were considered. At the Thirty-five years post-harvest, the highest yield was realized in the 50 percent treatment block (*table 1*). Total cumulative cubic foot volume per ac results differed slightly from board foot results. The highest two cumulative cubic foot volume per ac in thousands are for the 75 and 50 percent retention (25.0 and 24.6 respectively) with the control at 23.1 and 25 percent retention at 21.3.

Table 1—*Compilation of total yield at stand age 75 using thousand board feet volume (Mbf) per ac. Commercial thinning treatments retained a range of initial basal area (100 to 400 ft²/ac).*

Treatment	Age	Thousand board ft/ac volume		
		Cut	Standing	Cumulative
25%	41	31	17	48
	46		23	54
	51		32	63
	56		43	73
	62		53	84
	70		70	100
	75		78	109
50%	41	17	31	48
	46		40	57
	51		51	68
	56		64	81
	62		79	96
	70		100	117
	75		111	128
75%	41	5	40	46
	46		50	55
	51		61	66
	56		72	77
	62		85	90
	70		106	111
	75		116	121
100%	41	0	39	39
	46		49	49
	51		60	60
	56		73	73
	62		87	87
	70		105	105

Stand density

Stand Density Index (SDI) is a relative density measure that describes the level of inter-tree competition experienced by individual trees growing in a stand (Tappeiner and others 2007). The maximum theoretical SDI value for coast redwood is 1,000 (Reineke 1933) on an ac basis. The highest SDI value (887) was derived for the control in 2005 (*fig. 5*, above). The final SDI for 75 percent retention was 707. The final SDI for 25 and 50 percent retention treatments including regeneration were 385 and 556 respectively. The understory comprised about 22 percent of the entire SDI for 25 percent retention and 4 percent for the 50 percent retention.

Calculation of the SDI by the summation method provided lower values than those calculated in prior work (Lindquist 2004). Using the equation in prior studies; $SDI = TPA (D_q/10)^{1.605}$ where D_q is the quadratic mean diameter the result is 917 versus 887 for the control in 2005.

Understory regeneration

The redwood sprouting response after commercial thinning was inversely proportional to the overstory density. No sprouts were found in the un-thinned controls. The 75 percent retention plots had 5,130 redwood sprouts per ac in 1972. Twenty one years later these sprouts had diminished to the point that they did not merit further study (Lindquist 2004). The 25 and 50 percent retention plots had a similar number of sprouts initially (more than 10,000 sprouts/ac in 1972).

The regeneration measured in 25 percent retention treatment had a larger diameter than in the 50 percent retention treatment at the end of the study period as shown in *figures 6 and 7* ($P < .01$). Seedling in-growth tallied in 2007 had a higher proportion of western hemlock and grand fir than the first wave of regeneration in this study; 36 and 80 percent respectively in the 25 and 50 percent overstory retention treatments. After 35 years the 25 percent retention plots regeneration stems (> 4.5 inches DBH) was measured to be 451 cubic feet per ac.

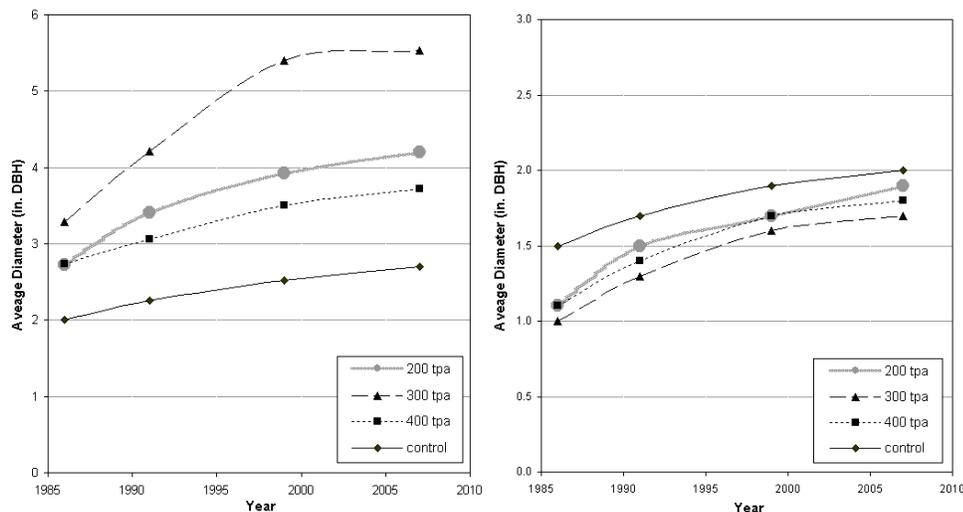


Figure 6 and 7—Growth of the redwood sprouts precommercially thinned to a range of densities within a commercially thinned to retain 100ft.²/ac of basal area per ac (*fig. 6*, left) or 200 ft.²/ac (*fig. 7*, right). Note the diameter scale for the 50 percent retention on the right is twice as large as the 25 percent retention on the left.

Discussion

As a result of the 35 year study period, each experimental treatment resulted in unique and quantifiable stand structures. The greatest mortality occurred in the control plots. Self thinning (onset of mortality) is expected to occur above an SDI of 550 (Tappeiner et al. 2007). The control was above this density threshold for the entire study period.

A substantial portion of the stems in the untreated control remained below the 10.5 inch threshold for production of board feet, but above the 4.5 inch threshold for cubic foot volume. Volume results vary between treatments depending on which volume measurement attributes were used.

The updated height estimation methodology resulted in slightly greater height estimates for the control trees than Lindquist's prior methods (2004). Diameter/height relationships in the study area are influenced both by site quality (plot basis used by Lindquist) and stand age (this study). Though height data is limited for early measurements, further exploration of this data could clarify results.

The 75 percent retention produced a total yield with slightly lower board foot volume than the 50 percent. The 75 percent retention consistently had the highest cubic foot MAI. Some sprouting was observed during the first decades after treatment, but the sprouts did not persist. O'Hara and Berrill (2010) noted complete sprout mortality at low light levels. The 75 percent retention surpassed the SDI threshold of 550 in 1980 and the first mortality was noted in 1985.

The 50 percent retention had quadric mean diameter of 26 inches at the end of the study period. This density level may offer log value or aesthetic benefits when the final diameters are compared to other treatments.

At the end of the study period the 35 year old stems under the 50 percent retention treatment averaged less than two inches in diameter. The SDI for this treatment exceeded the 550 threshold at the end of the 35 study period. Leaf area index is considered to be more integral to stand productivity and growing space occupancy than other measures (Berrill and O'Hara 2009). These authors conclude that removing a large fraction of the basal area such as this 50 percent treatment can promote a vigorous understory and high productivity. The observed slowing of understory diameter growth with time since treatment suggests that the reentry period is critical to maintaining understory vigor.

The 25 percent retention provides about 85 percent of the highest board foot yield (*table 1*), and has a mean diameter of 33 inches with an established understory. The initial 40 year old even aged stand had an average diameter of slightly over 10 inches in contrast to the now 35 year old regeneration with a treatment-wide average diameter of approximately four inches. This treatment does seem to provide a viable route to creating a multi-age stand if reentry periods are carefully planned.

Conclusion

The first phase of the Whiskey Springs commercial thinning study has concluded in 2011 with a second thinning. The next phase will have a demonstration and education objective because the plot size and corresponding edge effects make future

experimentation problematic at this site. The trees are now twice as tall as they were 35 years ago.

Long-term permanent plots in complex terrain present opportunities as well as challenges. An experimental site must provide adequate uniformity so that treatment effects are not confounded by site influences. Treatment buffers surrounding study plots need to be sufficient size to minimize edge effects. In addition, remeasurement must be continued over decades. The Whiskey Springs provided valuable research for the first 35 years. It confirms the importance of long-term studies and has provided insight beyond the original focus. A future California Forestry Note will include more details and additional analysis. The study area's resulting stand will continue to tangibly illustrate density management tradeoffs.

References

- Berrill, J.P.; O'Hara, K.L. 2009. **Simulating multiage coast redwood stand development: interactions between regeneration, structure, and productivity.** Western Journal of Applied Forestry 24(1): 24-32.
- Bawcom, R.; Hubbell, R.; Burns, D. 1961. **Seasonal diameter growth in trees on Jackson State Forest.** State Forest Note, No. 6. Sacramento, CA: Calif. Dept. of Forestry and Fire Protection. 5 p.
- Griffen, J.R. 1986. **Fall and buck study results: volume equations for Jackson State Forest.** JDSF Newsletter 22. Sacramento, CA: Calif. Dept. of Forestry and Fire Protection. 3 p.
- Krumland, B.; Eng, H. 2005. **Site index systems for major young-growth forest and woodlands species in northern California.** California Forestry Report No. 4. Sacramento, CA: Calif. Dept. of Forestry and Fire Protection. 219 p.
- Lindquist, J.L. 2004. **Growth & yield report for the Whiskey Springs redwood commercial thinning study. A twenty-nine year status report (1970-1999).** Calif. Forestry Report No. 3. Sacramento, CA: Calif. Dept. of Forestry and Fire Protection. 24 p.
- Lindquist, J.L. 1988. **Commercial thinning at Whiskey Springs Jackson Demonstration State Forest.** Calif. Dept. of Forestry and Fire Protection. Unpublished report. 23 p.
- Lindquist, J. L.; Palley, M.N. 1963. **Empirical yield tables for young-growth redwood.** Bull. 796. Berkeley, CA: Univ. of California College of Agriculture, Agricultural. Exp. Station. 47 p.
- O'Hara, K.L.; Berrill, J.P. 2010. **Dynamics of coast redwood sprout clump development in variable light environments.** Journal of Forest Research 15: 131-139.
- Oliver, W W.; Lindquist, J.; Strothmann, R. 1994. **Young-growth redwood stands respond well to various thinning intensities.** Western Journal of Applied Forestry 9(4): 106-112 p.
- Reineke, L.H. 1933. **Perfecting a stand-density index for even-aged forests.** Journal of Agricultural Research 46(7): 627-638.
- R Development Core Team. 2006. **R Version 2.2.0. A language and environment for statistical computing. R foundation for statistical computing.** www.R-project.org.
- Tappeiner, J.C.; Maguire, D.A.; Harrington, T.B. 2007. **Silviculture and ecology of western U.S. forests.** Corvallis, OR: Oregon State University Press. 440 p.

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Wensel, L.C.; Krumland, B.E.; Meerschaert, W.J. 1987. **CRYPTOS user's guide: the Cooperative Redwood Yield Project Timber Output Simulator**. Bull. 1924. Berkeley, CA: University of California Ag. Expt. Station, Division of Agriculture and Natural Resources. 89 p.