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Historical Growth Plots in the Pacific Southwest

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Abstract

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In the past, researchers from the Pacific Southwest Research Station (PSW) undertook forest growth studies to evaluate how best to manage timber resources. However, historical and future data collected at PSW growth plots also have the potential to increase our understanding of the ecological processes occurring in our forests and shed light on national issues of importance. This report provides information on the history, geography, plant species studied, installation, and measurement interval of each plot along with a list of publications arising from data gathered at these plots. This will enable current and future researchers to reidentify these plots and continue research at these locations.

Keywords: Growth and yield plots, levels of growing stock (LOGS), initial spacing, methods of harvest cuttings, long term soil productivity (LTSP), Garden of Eden.

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Background

Although the original intent in performing growth studies may have been to investigate treatment effects on growth and yield, historical data collections and data collected in the future can be analyzed to shed light on ecological processes occurring in our forests as well as on issues of national importance. Such issues include, but are not limited to, exploring the productivity of forests under different management scenarios and the potential for carbon sequestration. For this reason, studies using data from historical growth plots are important. Accordingly, this document details a variety of historical growth studies that have been established in California and southern Oregon to enable researchers to capitalize on, and build upon, the research legacy at these locations. Each of the studies described herein have been in place and maintained for more than a decade, and most have existed for much longer.

Historically, forest yield studies were undertaken to evaluate how best to manage timber resources and forecast productivity. Because the realization of forests yielding a product generally takes decades, foresters need to anticipate, or forecast yields over long timespans. Yield studies are designed to determine standing volume and tree dimensions for a forest plot at a given stage of stand development. By combining plots across a range of ages and site qualities, trends over time may be inferred, thus allowing managers to estimate the productive capacity of forest stands. The results of many early yield studies were expressed as yield (e.g., volume, or basal area) tables indexed by age and productivity as indicated by dominant height. These tabular values often were expressed graphically. Examples include Meyer (1938), Dunning and Reineke (1933), and Schumacher (1930, 1938). Tree diameter at breast height (dbh) generally is observed for all trees to provide an easily measured variable for estimating yield. To provide more precision, total height may be observed for all trees on a plot, or trees may be subsampled for total height systematically or randomly, depending on the method used. Upper stem diameter measurements also may be used to develop more precise estimates of volume.

The advantage of yield studies is that one may infer long-term trends of forest growth and mortality over time without investing decades of effort. However, there are some significant shortcomings. Correlation between site productivity and age can cause researchers to make incorrect inferences regarding trends in yield over time. Furthermore, tabular forecasts are not flexible, and they cannot express the effects of changing management practices or conditions, including climate change.

Variations in stand density, fertilization, prescribed fire, and competing vegetation control are all factors that may significantly alter rates of growth and mortality and change trajectories of stand development. Finally, single-point estimates are static and offer no insight into dynamic factors influencing forest growth at a specific location.

Some shortcomings of the static-yield approach may be avoided by observing growth over long periods on individual stands. Growth studies involve repeated measurements of plots over time. With repeated observations at individual plots under varying treatment regimes, growth and mortality may be related to management. Likewise, long-term impacts of varying management practices can be assessed. Typically, trees within a growth plot are remeasured at regular intervals, often every 5 to 10 years. When multiple resampling data sets are assembled in sequence, researchers can determine how trees within plots have grown or otherwise changed over the length of a study. They also may be able to make direct comparisons across treatments if the experiments are properly designed. Thus, the longer growth studies continue, the more utility they have in allowing researchers to understand the dynamics of forest growth. For growth studies, tree data commonly collected include dbh, total height, merchantable height, and crown ratio. A thorough reference of the procedures for establishing and maintaining these studies is Curtis and Marshall (2005).

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This document is divided into five sections representing the following kinds of growth studies/plots:

I. Levels-of-growing-stock (LOGS) studies
II. Spacing and growth studies
III. Garden of Eden studies
IV. Long-term soil productivity studies
V. Continuous forest inventory plots

Sections I through IV describe studies that were led by Pacific Southwest Research Station (PSW) scientists. Section V describes a set of plots that are managed and maintained by the California Department of Forestry and Fire Protection.

I. Levels-of-Growing-Stock (LOGS) Studies

The method used in LOGS studies allows researchers to measure growth over time at different stand densities. Plots are installed in a homogeneous, usually even-aged stand, and then thinned to various stand densities. Thinning is from below retaining the most vigorous, well-formed dominant and codominant trees as far as this is compatible with reasonably uniform spacing. The plots may or may not be periodically rethinned back to the original densities. The purpose is to determine stand growth and health resulting from various intensities of thinning. The LOGS studies have also demonstrated the influence of stand density on mortality, understory development, tree regeneration, and buildup of hazardous fuels.

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Some LOGS installations were established as a part of the West-Wide Levels-of-Growing-Stock Study of ponderosa pine. Work on this project began in the 1960s with a series of LOGS studies established in young even-aged stands throughout the West. Researchers, using a common study plan (Myers 1967), initiated studies in the Black Hills of South Dakota, eastern and central Oregon, the Coconino Plateau of Arizona, and the west-side Sierra Nevada in California. The study plan prescribes five or six growing stock levels (GSLs) replicated three times. These GSLs are the basal area in square feet per acre that the stand has, or will have, after thinning, when the quadratic mean diameter (QMD) is 10 in or more. Where QMDs are less than 10 in, the prescribed basal area for each GSL is tabulated in the study plan. As part of the West-Wide Levels of Growing Stock Study of ponderosa pine, PSW established the California installation (Elliot Ranch Plantation) and has assumed responsibility for the two in Oregon (Crawford Creek and Lookout Mountain) following their abandonment by the Pacific Northwest Research Station. Growing-stock studies similar in many respects to the prototype effort, but expanded to other species, are described as well. Both the West-Wide Levels of Growing Stock installations and other LOGS-type installations managed by PSW are described below (see fig. 1 for plot locations):

Big Lake (LOGS)

History—

This study (fig. 2) was installed by the U.S. Department of Agriculture, Forest Service, Pacific Southwest Regional Office's Silviculture Development Unit to demonstrate best practices in commercially thinning true fir stands. Merchantable logs were skidded to roadside with a small crawler tractor and the slash was lopped and scattered over the plot. Following the thinning, Annosus root rot (*Heterobasidion annosum*) was active in killing trees for several years but is now inactive. Plots were rethinned in 1989 as described in table 1.

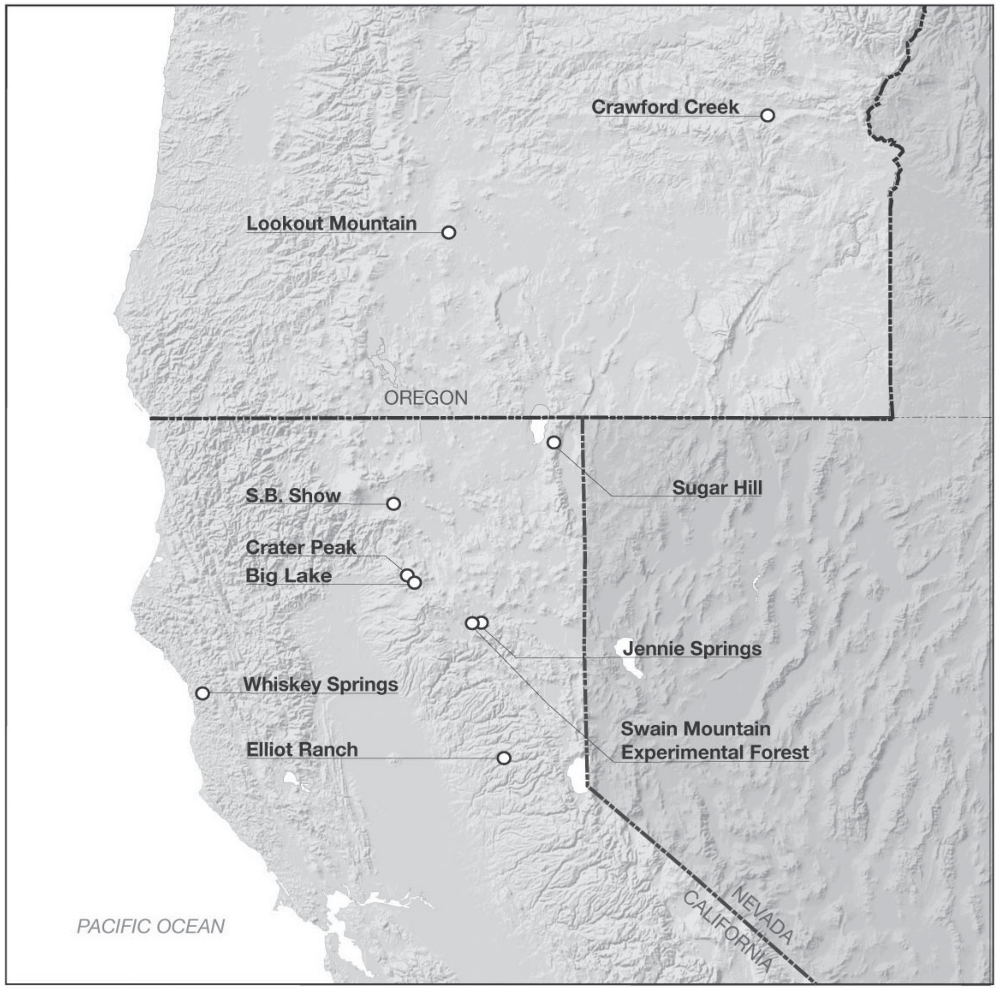

Figure 1—Levels-of-growing-stock plots in California.

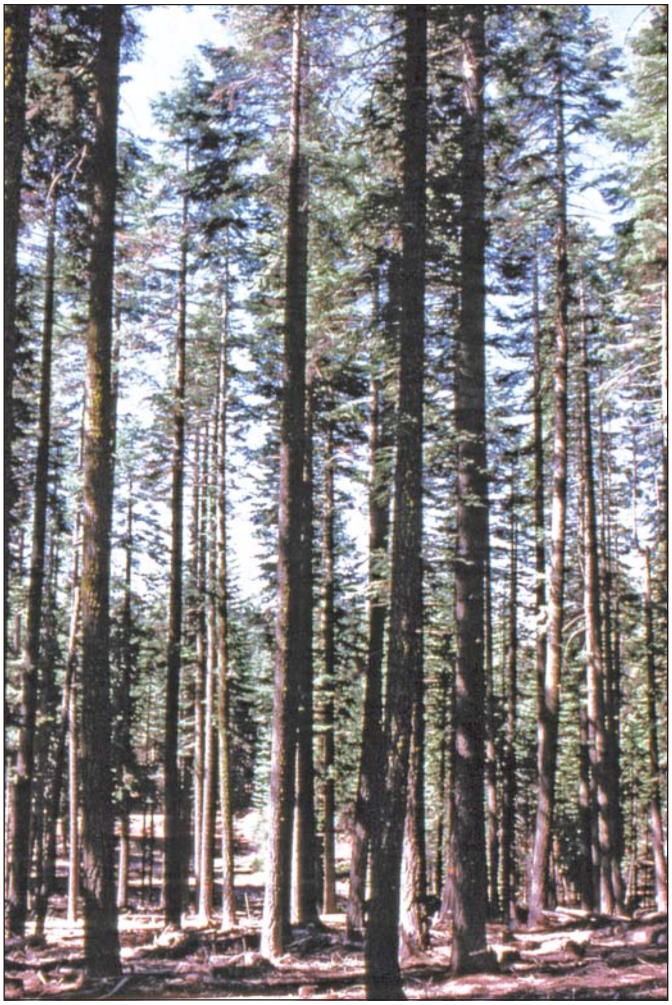

Figure 2—Big Lake levels-of-growing-stock plot 7 in 1990. Plot was rethinned to 233 ft^2 in 1998.

Table 1—Big Lake 1989 rethinning treatments

Plot	Original treatment	Retreatment
	Percent of normal[a]	*Square feet*
1	55	180
2	70	280
3	40	100
4	40	100
5	70	280
6	Control	388
7	70	233[b]
8	Control	326

[a] Schumacher 1926.

[b] Plot 7 was rethinned to 55 percent of normal (233 ft^2) rather than to 280 ft^2 of basal area because researchers wished to continue to use the area for field trips and to show this common thinning prescription.

- Location—Sec. 15, T. 32 N, R. 3 E. on the Hat Creek Ranger District of the Lassen National Forest
- Latitude/longitude—Lat. 40.62 N.; long. 121.63 W.
- Elevation—5,900 ft
- Soil parent material—Basalt
- Species studied—White fir (*Abies concolor* (Gord. & Glend.) Lindl. ex. Hildebr.)
- Duration of data collection—1976-ongoing
- Measurement interval—5 years

Study design—
The plots are 0.5 ac and buffered with a 30-ft isolation strip. Treatments were assigned in a fully randomized design with two replications. Stand densities tested were percentages of the basal area shown in the Schumacher (1926) yield table for that site and stand age (table 1).

Measurements—
All trees within the plots were measured for dbh. Stem deformities and evidence of insect and disease attack were also noted. Total height and height to live crown were measured on a 20-percent systematic sample of the trees. A probability-proportional-to-size sample of six trees per plot was measured with a Barr and Stroud optical dendrometer for stem volumes during several remeasurements.

Monumentation—
All measurement trees are tagged at breast height. Originally, trees just inside the measurement plot boundary were banded with colors coded to the treatment: red = control; blue = 40 percent of normal basal area stand density; orange = 55 percent of normal basal area stand density; and yellow = 70 percent of normal basal area stand density. In 1993, all boundary trees were rebanded in yellow regardless of treatment. Trees sampled for total height are double banded. Plot corners are monumented with T-fenceposts color coded as above.

Publications that used data from this study—
Cochran, P.H.; Oliver, W.W. 1988. Growth rates for managed stands of white fir. In: Schmidt, W.C., comp. Proceedings, Future forests of the mountain west: a stand culture symposium. Gen. Tech. Rep. INT-243. Missoula, MT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 197–200.

Zhang, J.W.; Oliver, W.W.; Ritchie, M.W. 2007. Effect of stand densities on stand dynamics in white fir (*Abies concolor*) forests in northeast California, USA. Forest Ecology and Management. 244: 50–59.

Crater Peak (LOGS)

History—

This installation was part of the Pacific Southwest Regional Office's Silviculture Development Unit's commercial thinning investigations. Plots were rethinned in 1989 as reported in table 2.

- Location—NW1/4 of the NE1/4 of sec. 17, T. 33 N., R. 3 E. on the Hat Creek Ranger District of the Lassen National Forest
- Latitude/longitude—Lat. 40.72 N; long. 121.67 W.
- Elevation—5,300 ft
- Species studied—White fir
- Soil parent material—Volcanic pyroclastics
- Duration of data collection—1978-ongoing
- Measurement interval—5 years

Study design—

The plots are 0.5 ac and buffered with a 30-ft isolation strip. Treatments were assigned in a fully randomized design with three replications. Stand densities tested were percentages of the basal area shown in the Schumacher (1926) yield table for that site and stand age.

Measurements—

All trees within the plots were measured for dbh. Stem deformities and evidence of insect and disease attack were also noted. Total height and height to live crown were measured on a 20-percent systematic sample of the trees. A probability-proportional-to-size sample of six trees per plot was measured with a Barr and Stroud optical dendrometer for stem volumes during several remeasurements.

Monumentation—

All measurement trees are tagged at breast height. Originally, trees just inside the measurement plot boundary were banded with colors coded to the treatment: blue = 40 percent of normal basal area stand density; orange = 55 percent of normal basal area stand density; and yellow = 70 percent of normal basal area stand density. In 1993 all boundary trees were rebanded in yellow regardless of treatment. Trees sampled for total height are double banded. Plot corners are monumented with T-fenceposts color coded as above.

Table 2—Crater Peak 1989 rethinning treatments

Plot	Original treatment	Retreatment
	Percent of normal[a]	*Ft^2/ac*
1	70	280
2	55	180
3	40	100
4	70	280
5	55	180
6	40	100
7	40	100
8	55	180
9	70	280

[a] Schumacher 1926.

Publications that used data from this study—

Cochran, P.H.; Oliver, W.W. 1988. Growth rates for managed stands of white fir. In: Schmidt, W.C., comp. Proceedings, Future forests of the mountain west: a stand culture symposium. Gen. Tech. Rep. INT-243. Missoula, MT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 197-200.

Zhang, J.W.; Oliver, W.W.; Ritchie, M.W. 2007. Effect of stand densities on stand dynamics in white fir (*Abies concolor*) forests in northeast California, USA. Forest Ecology and Management. 244: 50-59.

Crawford Creek (LOGS)

History—

In addition to the LOGS studies in California reported in this document, PSW also maintains the LOGS study on the Malheur National Forest that was originally established by the Pacific Northwest Research Station. The Crawford Creek LOGS study (fig. 3) was established as part of the West-Wide Levels of Growing-Stock Study for even-aged ponderosa pine (Myers 1967). It was established in 1967 in a naturally regenerated, 60-year-old stand. Thinning slash was lopped and scattered. Plots were rethinned back to the originally assigned GSLs after the second measurement period in 1977. After the fourth remeasurement in 1986, GSLs were changed to stand density index (SDI) values of 55, 110, 147, 183, 220, and 257. These values are equivalent to the original GSLs when the QMD is 10 in. High mortality rates from mountain pine beetles (*Dendroctonus ponderosae* Hopkins) occurred on some plots where values for stand density index exceeded 140.

Figure 3—Crawford Creek levels-of-growing-stock plot in 1987 thinned to GSL 80.

- Location—Sec. 11, 12, 14, 15, 22, 26, and 27, T. 11 S., R. 35 E. Willamette Meridian on the Blue Mountain Ranger District, Malheur National Forest
- Latitude/longitude—Lat. 44.60 N.; long. 118.44 W.
- Elevation—4,400 ft
- Soil parent material—Mazama ash
- Species studied—Ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.)
- Duration of data collection—1967-ongoing
- Measurement interval—5 years

Study design—

The plots are grouped into three blocks on gentle slopes of all aspects within the Crawford Creek drainage. Plots are 0.4 or 0.5 ac and buffered with a 33-ft isolation strip. Six GSLs were assigned in a randomized complete block design with three replications totaling 18 plots. The GSLs are the basal area in square feet per acre that the stand has, or will have, after thinning, when the QMD is 10 in or more. Where QMDs are less than 10 in, the prescribed basal area for each GSL is tabulated in the study plan. Assigned GSLs were 30, 60, 80, 100, 120, and 140.

Measurements—

All trees within the measurement plots were measured for dbh. Fifteen trees on each thinned plot were selected for measuring with an optical dendrometer for total height and stem volume determinations. Trees from each diameter class were randomly selected so that the complete range of diameter classes was equally represented.

Monumentation—

All measurement trees are tagged at breast height.

Publications that used data from this study—

Barrett, J.W. 1979. Silviculture of ponderosa pine in the Pacific Northwest: the state of our knowledge. Gen. Tech. Rep. PNW-97. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 106 p.

Cochran, P.H.; Barrett, J.W. 1995. Growth and mortality of ponderosa pine poles thinned to various densities in the Blue Mountains of Oregon. Res. Pap. PNW-RP-483. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 27 p.

DeMars, D.J.; Barrett, J.W. 1987. Ponderosa pine managed-yield simulator: PPSIM users guide. Gen. Tech. Rep. PNW-GTR-203. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 36 p.

Edminster, C.B. 1988. Stand density and stocking in even-aged ponderosa pine stands. In: Baumgartner, D.M.; Lotan, J.E., comps. Proceedings, ponderosa pine the species and its management. Pulman, WA: Washington State University: 253–260.

Oliver, W.W.; Edminster, C.B. 1988. Growth of ponderosa pine thinned to different stocking levels in the Western United States. In: Schmidt, W.C., comp. Proceedings, Future forests of the mountain west: a stand culture symposium. Gen. Tech. Rep. INT-243. Missoula, MT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 153–159.

Oliver, W.W. 2005. The West-Wide Ponderosa Pine Levels-of-Growing-Stock Study at age 40. In: Ritchie, M.W.; Maguire, D.A.; Youngblood, A., tech. cords. Proceedings, symposium on ponderosa pine: issues, trends, and management. Gen. Tech. Rep. PSW-198. Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station: 71–80.

Elliot Ranch Plantation (LOGS)

History—

This plantation (fig. 4) originated in 1949 after the Elliot Ranch Fire, which burned a deerbrush (*Ceanothus integerrimus*) brush and snag field that had developed following the 1949 Elliot Ranch Burn. This is one of six installations in the West-Wide Levels-of-Growing-Stock Study for even-aged ponderosa pine guided by Myers' (1967) study plan. Portions of the Elliot Ranch plantation were used in developing yield tables for managed stands of ponderosa pine (Oliver and Powers 1978).

- Location—SW 1/4 of sec. 9, T.15. N., R.11 E. on the Foresthill Ranger District, Tahoe National Forest
- Latitude/longitude—Lat. 39.16 N.; long. 120.74 W.
- Elevation—4,000 ft
- Soil parent material—Tuff breccia and stratified sands and gravels
- Species studied—Ponderosa pine
- Plot installation—1969
- Duration of data collection—1969-ongoing
- Measurement interval—5 years

Study design—

All plots are buffered with a 30-ft isolation strip. The study design is fully randomized with three replications. All plots are 0.5 ac, exclusive of buffer. Five GSLs of 40, 70, 100, 130, and 160 were applied in 1969. The GSLs are the basal area in square feet per acre that the stand has, or will have, after thinning, when the QMD is 10 in or more. Where QMDs are less that 10 in, the prescribed basal area for each GSL is tabulated in the study plan. Rethinnings in 1974 and 1979 restored the original GSLs. The third rethinning in 1989 used SDI as the measure of stand density and resulted in an approximately 10-percent increase in growing stock for each density treatment.

Measurements—

All trees within the plots were measured for dbh. Stem deformities and evidence of insect and disease attack were also noted. Total height and height to live crown was measured on a 20-percent systematic sample of the trees during all but the last measurement in 2004. At that time, all trees were measured for total height. Height to live crown measurements were discontinued in 2004. A probability-proportional-to-size sample of six trees per plot was measured with a Barr and Stroud optical dendrometer for stem volumes during several remeasurements.

Figure 4—Elliot Ranch levels-of-growing-stock plot 15 after rethinning to 90 ft^2 basal area in 1989.

Monumentation—

All trees in the plots are included as measurement trees and are tagged at breast height. All measurement trees are banded in yellow, and height sample trees have a double yellow band. Tag numbers are unique for each tree throughout the study. Plot corners were monumented with T-fenceposts or with 4 by 4 cedar posts. The Foresthill Ranger District posted signs at each plot that show the respective plot numbers with a sign nearby describing the study.

Publications that used data from this study—

Oliver, W.W. 1980. Growth of planted ponderosa pine thinned to different stocking levels in northern California. Res. Pap. PSW-147. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. 11 p.

Oliver, W.W. 1995. Is self-thinning of ponderosa pine ruled by *Dendroctonus* bark beetles? In: Eskew, L.G., comp. Forest health through silviculture. Proceedings of the 1995 national silviculture workshop. Gen. Tech. Rep. RM-267. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 213–218.

Oliver, W.W. 1997. Twenty-five-year growth and mortality of planted ponderosa pine repeatedly thinned to different stand densities in northern California. Western Journal of Applied Forestry. 12(4): 122–130.

Oliver, W.W. 2005. The west-wide ponderosa pine levels-of-growing-stock study at age 40. In: Ritchie, M.W.; Maguire, D.A.; Youngblood, A., technical cords. Proceedings, Symposium on ponderosa pine: issues, trends and management. Gen. Tech. Rep. PSW-198. Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station: 71–80.

Oliver, W.W.; Dolph, K.L. 1992. Mixed-conifer seedling growth varies in response to overstory release. Forest Ecology and Management. 48: 179–183.

Oliver, W.W.; Edminster, C.B. 1988. Growth of ponderosa pine thinned to different stocking levels in the Western United States. In: Schmidt, W.C., comp. Proceedings, Future forests of the mountain west: a stand culture symposium. Gen. Tech. Rep. INT-243. Missoula, MT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 153–159.

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Oliver, W.W.; Powers, R.F. 1971. Early height growth of ponderosa pine forecasts dominance in plantations. Res. Note PSW-250. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station. 4 p.

Oliver, W.W.; Powers, R.F. 1978. Growth models for ponderosa pine: I. Yield of unthinned plantations in northern California. Res. Pap. PSW-133. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station. 21 p.

Oliver, W.W.; Uzoh, F.C.C. 1997. Maximum stand densities for ponderosa pine and red and white fir in northern California. In: Proceedings, 18th annual forest vegetation management conference. Redding, CA: University of California Cooperative Extension: 57–65.

Powers, R.F.; Oliver, W.W. 1970. Snow breakage in a pole-sized ponderosa pine plantation…more damage at high densities. Res. Note PSW-218. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. 3 p.

Sindel, G.E. 1963. The use of cattle to control deerbrush growth during pine plantation establishment. Society of American Foresters Proceedings. 1962: 71–72.

Uzoh, F.C.C.; Oliver, W.W. 2006. Individual tree height increment model for managed even-aged stands of ponderosa pine throughout the Western United States using linear mixed effects models. Forest Ecology and Management. 221: 147–154.

Jennie Springs (LOGS)

History—

This 80-ac stand of natural origin (fig. 5) lies on a very gentle south-facing slope and is exceptionally uniform in site quality. Levels of growing stock is only one feature of the multifaceted study that was initiated at this location. The study, as originally envisioned, was to include investigations of all the intensive silvicultural operations currently operational in true fir stands in California. These included density control, fertilization, and prescribed fire both pre- and postharvest to reduce fuel loads and to break dormancy on shrub seeds. Slash was lopped and scattered over the plots. Merchantable logs were skidded by horses to the road side. At present, only the LOGS study is actively maintained.

- Location—N1/2 of sec. 4, T. 29 N., R. 8 E., MDM on the southern flank of Swain Mountain near Jennie Springs on the Almanor Ranger District, Lassen National Forest
- Latitude/longitude—Lat. 40.40 N.; long. 121.09 W.
- Elevation—6,100 ft
- Soil parent material—Basalt
- Species studied—White fir
- Plot installation—1981
- Duration of data collection—1981-ongoing
- Measurement interval—5 years

Study design—

All plots are square, 0.49 ac, and buffered by a 30-ft isolation strip. The study design is fully randomized with three replications of five basal area stand densities—80, 130, 180, 230, and unthinned at 385 ft^2/ac. The plots have not been rethinned.

Measurements—

All trees within the plots were measured for dbh. Stem deformities and evidence of insect and disease attack were also noted. Total height and height to live crown was measured on a 20-percent systematic sample of the trees. A probability-proportional-to-size sample of six trees per plot was measured with a Barr and Stroud optical dendrometer for stem volumes during several remeasurements.

Monumentation—

All measurement trees in the thinned plots are tagged at breast height and banded in yellow. Trees originally selected for height measurements are double banded in yellow. In the unthinned plots, every other tree was tagged. No permanent corner posts were set.

Figure 5—Jennie Springs levels-of-growing-stock plot 9 in 1986 thinned to 230 ft^2 basal area.

Publications that used data from this study—

Cochran, P.H.; Oliver, W.W. 1988. Growth rates for managed stands of white fir. In: Schmidt, W.C., comp. Proceedings, Future forests of the mountain west: a stand culture symposium. Gen. Tech. Rep. INT-243. Missoula, MT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 197–200.

Fieber, W.; Robson, T. 1985. Jennie Springs…Horse logging as a new enterprise. Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Region. 20 p.

Waters, J.R.; McKelvey, K.S.; Zabel, C.J.; Oliver, W.W. 1994. The effects of thinning and broadcast burning on sporocarp production of hypogeous fungi. Canadian Journal of Forest Research. 24: 1516–1522.

Zhang, J.W.; Oliver, W.W.; Ritchie, M.W. 2007. Effect of stand densities on stand dynamics in white fir (*Abies concolor*) forests in northeast California, USA. Forest Ecology and Management. 244: 50–59.

Lookout Mountain (LOGS)

History—

In addition to the LOGS studies in California reported in this document, PSW Research Station also maintains the LOGS study on Lookout Mountain (fig. 6) that was originally established by the Pacific Northwest Research Station. The Lookout LOGS study was established as part of the West-Wide Levels of Growing-Stock study for even-aged ponderosa pine (Myers 1967). The study was established in 1965 in a naturally regenerated 1,000-ac stand. Thinning slash was lopped and scattered. Plots were rethinned back to the originally assigned GSLs after the second measurement period in 1975. After the fourth remeasurement in 1985, GSLs were changed to SDI values of 55, 110, 147, 183, 220, and 275. These values are equivalent to the original GSLs when the QMD is 10 in. Mortality has been minor and attributed to mountain pine beetles (*Dendroctonus ponderosae* Hopkins) attacking weakened trees in the denser plots. Pandora moth (*Coloradia pandora* Blake) caused partial defoliation during 1992 and 1994, which reduced growth rates during those years.

- Location—Sec. 4, 5, 6, T. 21 S., R. 9 E. Willamette Meridian on Lookout Mountain, Pringle Falls Experimental Forest, Oregon
- Latitude/longitude—Lat. 43.77 N.; long. 121.72 W.
- Elevation—5,000 ft
- Soil parent material—Dacite pumice 3 ft deep over older volcanic ash
- Species studied—Ponderosa pine
- Duration of data collection—1965–ongoing
- Measurement interval—5 years

Study design—

The plots were scattered throughout a quarter section on a south-facing slope where site and stand density differences could be minimized. Plots are 0.5 ac and buffered with a 33-ft isolation strip. Six GSLs were assigned in a fully randomized design with three replications totaling 18 plots. The GSLs are the basal area in square feet per acre that the stand has, or will have, after thinning, when the QMD is 10 in or more. Where QMDs are less than 10 in, the prescribed basal area for each GSL is tabulated in the study plan. Assigned GSL levels were 30, 60, 80, 100, 120, and 150.

Figure 6—Lookout Mountain levels-of-growing-stock plot in 1979 after rethinning to GSL 100.

Measurements—

All trees within the plots were measured for dbh. Fifteen trees on each thinned plot were selected for measuring with an optical dendrometer for total height and stem volume determinations. Trees were randomly selected from each diameter class so that the complete range of diameter classes was equally represented.

Monumentation—

All measurement trees are tagged at breast height.

Publications that used data from this study—

Barrett, J.W. 1979. Silviculture of ponderosa pine in the Pacific Northwest: the state of our knowledge. Gen. Tech. Rep. PNW-97. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 106 p.

Barrett, J.W. 1983. Growth of ponderosa pine poles thinned to different stocking levels in central Oregon. Res. Pap. PNW-311. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 9 p.

Cochran, P.H.; Barrett, J.W. 1999. Growth of ponderosa pine thinned to different stocking levels in central Oregon: 30-year results. Res. Pap. PNW-RP-508. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 27 p.

DeMars, D.J.; Barrett, J.W. 1987. Ponderosa pine managed-yield simulator: PPSIM users guide. Gen. Tech. Rep. PNW-GTR-203. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 36 p.

Edminster, C.B. 1988. Stand density and stocking in even-aged ponderosa pine stands. In: Baumgartner, D.M.; Lotan, J.E., comps. Proceedings, Ponderosa pine the species and its management. Pulman, WA: Washington State University: 253–260.

Oliver, W.W.; Edminster, C.B. 1988. Growth of ponderosa pine thinned to different stocking levels in the Western United States. In: Schmidt, W.C., comp. Proceedings, Future forests of the mountain west: a stand culture symposium. Gen. Tech. Rep. INT-243. Missoula, MT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 153–159.

Oliver, W.W. 2005. The west-wide ponderosa pine levels-of-growing-stock study at age 40. In: Ritchie, M.W.; Maguire, D.A.; Youngblood, A., tech. cords. Proceedings, Symposium on ponderosa pine: issues, trends, and management. Gen. Tech. Rep. PSW-198. Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station: 71–80.

S. B. Show Plantation (LOGS)

History—

This plantation was established in 1919 by S.B. Show and is thought to be the oldest successful ponderosa pine plantation in California (fig. 7). For many years it was a popular show piece for visiting land managers, and stem analyses made from temporary plots were used in developing site index curves (Powers and Oliver 1978) and yield tables (Oliver and Powers 1978) for managed stands of ponderosa pine. The thinning plots were established by the Pacific Southwest Regional Office as part of an administrative study of growth responses to operational commercial thinning. The McCloud Ranger District underburned the plantation in spring 1995, consuming a light cover of grass and needle litter. Over the life of the study, black stain root disease (*Leptographium wageneri*) has weakened many trees leading to killing by mountain pine beetle. As a result, net growth of the stand has been slow.

Figure 7—S. B. Show Plantation levels-of-growing-stock plot 1 in 1968 before thinning to 152 ft^2 basal area.

- Location—NE1/4 of the SE1/4, sec. 8, T. 41 N., R. 1 W. on the McCloud Ranger District, Shasta-Trinity National Forests
- Latitude/longitude—Lat. 41.32 N.; long. 121.98 W.
- Elevation—3,900 ft
- Soil parent material—Volcanic ash over basalt
- Species studied—Ponderosa pine
- Plot installation—1972
- Duration of data collection—1972-ongoing

Study design—

Three unreplicated and unbuffered 1-ac plots were thinned to 40, 55, and 70 percent of that shown in Meyer's (1938) yield table for stands of that age and site quality. Basal area equivalents were 85, 103, and 152 ft^2/ac. The plots have not been rethinned.

Measurements—

All trees within the plots were measured for dbh. Stem deformities and evidence of insect and disease attack were also noted. Total height and height to live crown was measured on a 20-percent systematic sample of the trees. A probability-proportional-to-size sample of six trees per plot was measured with a Barr and Stroud optical dendrometer for stem volumes during several remeasurements.

Monumentation—

All measurement trees are tagged and banded in yellow at breast height. Trees sampled for height are double banded in yellow. Subsequent to plot installation, the Weyerhaeuser Co. superimposed a growth and yield plot over plot 1 as part of their growth and yield study of ponderosa pine plantations.[1] As a result, some trees have two tags and a confusing array of paint stripes and bands. The measurement trees in this study use a stamped oblong aluminum tag, and Weyerhaeuser Co. study trees used an embossed aluminum tag. T-fenceposts originally marked plot corners, but most have disappeared.

Publications that used data from this study—

Oliver, W.W. 1995. Is self-thinning of ponderosa pine ruled by *Dendroctonus* bark beetles? In: Eskew, L.G., comp. Forest health through silviculture. Proceedings, 1995 national silviculture workshop. Gen. Tech. Rep. RM-267. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 213–218.

Oliver, W.W.; Powers, R.F. 1978. Growth models for ponderosa pine: I. Yield of unthinned plantations in northern California. Res. Pap. PSW-133. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station. 21 p.

Oliver, W.W.; Uzoh, F.C.C. 1997. Maximum stand densities for ponderosa pine and red and white fir in northern California. In: Proceedings, 18th annual forest vegetation management conference. Redding, CA: University of California Cooperative Extension: 57–65.

Powers, R.F.; Oliver, W.W. 1978. Site classification of ponderosa pine under stocking control in California. Res. Pap. PSW-128. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station. 9 p.

Uzoh, F.C.C.; Oliver, W.W. 2006. Individual tree height increment model for managed even-aged stands of ponderosa pine throughout the Western United States using linear mixed effects models. Forest Ecology and Management. 221: 147–154.

[1] The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

Sugar Hill Plantation (LOGS)

History—

The Sugar Hill Plantation (fig. 8), on the north side of Sugar Hill and on the west side of the Warner Mountains, is the largest successful ponderosa pine plantation in California. It was established between 1931 and 1945 by the Civilian Conservation Corp, the Civilian Public Service, and the Modoc National Forest after a series of devastating fires. Six plots were installed on flat land or gentle slopes at the base of Sugar Hill in the areas planted in 1932. Plots 1 and 2 were originally crop-tree thinned (plot 1—tree spacing three times dbh + four expressed in feet and plot 2—tree spacing two times dbh + four expressed in feet). Plots were converted to area thinning using stem analysis to reconstruct the early growth of the unmeasured trees within the interstices. Plots 3, 4, and 5 were thinned to 100, 200, and 300 trees per acre, respectively. Plot 6 was left unthinned. Slash was lopped and scattered on all plots. The plots have not been rethinned. The surrounding stands were operationally thinned over a 4-year period from 1991 to 1994.

Beginning in 1974 and continuing for 10 years, mountain pine beetles (*Dendroctonus monticola*) killed many trees in the unthinned plot 6, eventually reducing the stand density below SDI 300. Similar killing began in 1989 in plot 4, thinned to 200 trees per acre, and was continuing in 2005, also reducing the SDI below 300. These episodes dramatically demonstrated the need to control stocking

Figure 8—Sugar Hill Plantation levels-of-growing-stock plot 2 in 1971 thinned to 80 trees per acre.

in ponderosa pine to maintain stand health. Unthinned portions of the Sugar Hill plantation were used in developing yield tables for managed stands of ponderosa pine (Oliver and Powers 1978).

- Location—Plots 1, 2, 3, 5, and 6 are in the N1/2 of sec. 13 and plot 4 is in the SE1/4 of sec. 13, T. 46 N., R. 14 E. on the south side of Lassen Creek, north of Sugar Hill, on the Warner Mountain Ranger District, Modoc National Forest
- Latitude/longitude—Lat. 41.83 N.; long. 120.3 W.
- Elevation—5,400 ft
- Soil parent material—Obsidian
- Species studied—Ponderosa pine and Jeffrey pine (*Pinus jeffreyi* Grev. & Balf.)
- Plot installation—1958–59
- Duration of data collection—1959-ongoing
- Measurement interval—4 to 6 years

Study design—

All plots are unbuffered and unreplicated. Plot sizes, stand density treatment, and initial species composition can be found in table 3.

Measurements—

All trees within the plots were measured for dbh. Stem deformities and evidence of insect and disease attack were also noted. Total height and height to live crown was measured on a 20-percent systematic sample of the trees during all but the first measurement in 1958-59 and the last measurement in 2004. At those times, all trees were measured for total height. Height to live crown was measured during the 1965 through 1999 measurements. A probability-proportional-to-size sample of six trees per plot was measured with a Barr and Stroud optical dendrometer for stem volumes during several remeasurements.

Monumentation—

All measurement trees are tagged at breast height. Most plot corners are monumented by metal fenceposts. All measurement trees are banded in yellow, and height sample trees have a double yellow band.

Table 3—Sugar Hill Plantation plot size, target density, and initial species composition

Plot	Size	Basal area	Species composition	
			Ponderosa pine	Jeffrey pine
No.	*Ac*	*Ft^2/ac*	– – – – – – *Percent* – – – – – –	
1	1.356	13	100	0
2	2.0	25	86	14
3	1.0	25	81	19
4	.75	66	100	0
5	1.0	85	0	100
6	1.0	74	89	11

Publications that used data from this study—

Oliver, W.W. 1972. Growth after thinning ponderosa and Jeffrey pine pole stands in northeastern California. Res. Pap. PSW-85. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station. 8 p.

Oliver, W.W. 1979. Fifteen-year growth patterns after thinning a ponderosa-Jeffrey pine plantation in northeastern California. Res. Pap. PSW-141. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station. 10 p.

Oliver, W.W. 1995. Is self-thinning of ponderosa pine ruled by *Dendroctonus* bark beetles? In: Eskew, L.G., comp. Forest health through silviculture. Proceedings, 1995 national silviculture workshop. Gen. Tech. Rep. RM-267. Forest Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 213–218.

Oliver, W.W.; Ferrell, G.T.; Tappeiner, J.C. 1996. Density management of Sierra Nevada forests. In: Sierra Nevada ecosystem project: final report to Congress. Vol. III, assessments, commissioned reports, and background Information. Davis, CA: University of California, Center for Water and Wildland Resources: 491–500.

Oliver, W.W.; Powers, R.F. 1978. Growth models for ponderosa pine: I. Yield of unthinned plantations in northern California. Res. Pap. PSW-133. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station. 21 p.

Oliver, W.W.; Trask, J. 1983. Responses of eastside pine to precommercial thinning. In: Proceedings, Symposium on management of the eastside pine type in northeastern California. Reno, NV: Cooperative Extension, University of California and Northern California Society of American Foresters: 107–113.

Oliver, W.W.; Uzoh, F.C.C. 1997. Maximum stand densities for ponderosa pine and red and white fir in northern California. In: Proceedings, 18th annual forest vegetation management conference. Redding, CA: University of California Cooperative Extension: 57–65.

Uzoh, F.C.C.; Oliver, W.W. 2006. Individual tree height increment model for managed even-aged stands of ponderosa pine throughout the Western United States using linear mixed effects models. Forest Ecology and Management. 221: 147–154.

Swain Mountain Experimental Forest (LOGS)

History—

This small stand (fig. 9) on a gentle northwest-facing slope originated from a fire over 100 years before the study was established, leaving a scattering of large old trees that were removed several years before the study was established. Merchantable logs were skidded to roadside using a rubber-tired grapple skidder. Slash was piled and burned in the buffer areas. The grapple skidder wounded about 10 percent of the residual trees. Most of the wounded trees were removed in the rethinning. Annosus root rot spreading from these old remnants killed some trees in plot 10 during the first few years after the study was established. Plots were rethinned in November 1996 using SDI as the measure of stand density. Target densities for the thinned plots were SDIs of 180, 230, 280, 330, 380, and unthinned at 651.

- Location—SE1/4, sec. 30, T. 30 N., R. 8 E. within the Swain Mountain Experimental Forest
- Latitude/longitude—Lat. 40.43 N.; long. 121.12 W.
- Soil parent material—Basalt
- Elevation—6,400 ft
- Species studied—Mixed white fir and red fir (*Abies magnifica* A. Murr.)
- Plot installation—1975
- Duration of data collection—1975-ongoing
- Measurement interval—5 years

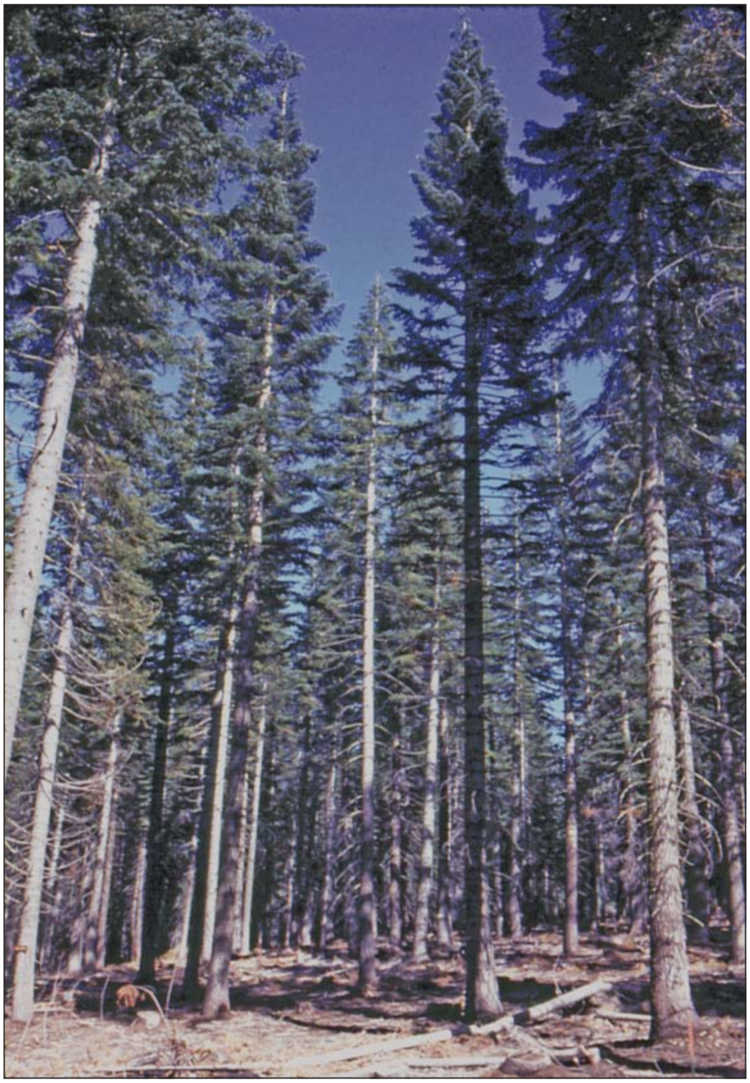


Figure 9—Swain Mountain Experimental Forest levels-of-growing-stock plot 8 in 1977 originally thinned to140 ft^2 basal area.

Study design—

The twelve 0.5-ac plots are buffered by an isolation strip at least 33 ft wide. The study design is full randomized with two replications of five basal area stand densities—140, 170, 200, 230, 260 and unthinned at 367 ft^2/ac.

Measurements—

All trees within the plots were measured for dbh. Stem deformities and evidence of insect and disease attack were also noted. Total height and height to live crown was measured on a 20 percent systematic sample of the trees. A probability-proportional-to-size sample of six trees per plot was measured with a Barr and Stroud optical dendrometer for stem volumes during several remeasurements.

Monumentation—

All measurement trees are tagged and banded in yellow. Height sample trees have double yellow bands. T-fenceposts marked the plot corners originally but have mostly disappeared.

Publications that used data from this study—

Cochran, P.H.; Oliver, W.W. 1988. Growth rates for managed stands of white fir. In: Schmidt, W.C., comp. Proceedings, Future forests of the mountain west: a stand culture symposium. Gen. Tech. Rep. INT-243. Missoula, MT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 197–200.

Oliver, W.W. 1988. Ten-year growth response of a California red and white fir sawtimber stand to several thinning intensities. Western Journal of Applied Forestry. 3(2): 41–43.

Oliver. W.W.; Ferrell, G.T.; Tappeiner, J.C. 1996. Density management of Sierra Nevada forests. In: Sierra Nevada ecosystem project: final report to Congress. Vol. III, assessments, commissioned reports, and background information. Davis, CA: University of California, Center for Water and Wildland Resources: 491–500.

Zhang, J.W.; Oliver, W.W.; Ritchie, M.W. 2007. Effect of stand densities on stand dynamics in white fir (*Abies concolor*) forests in northeast California, USA. Forest Ecology and Management. 244: 50–59.

Whiskey Springs (LOGS)

History—

The Whiskey Springs study was planned in conjunction with the California Department of Forestry and Fire Protection on the Jackson Demonstration State Forest near Fort Bragg, California. This dense second-growth redwood stand (fig. 10) originated from sprouts following clearcutting in late 1928. Evidence suggests that some trees originated from planting. The merchantable logs were skidded from the study plots by crawler tractors. Slash was lopped and scattered on the plots.

Figure 10—Whiskey Springs levels-of-growing-stock study. This general view was photographed in 1995.

- Location—Whiskey Springs, along Truck Road (just west of the Whiskey Springs Residence; At milepost 9.5, approximately 1,000 ft south of Highway 20) on the Jackson Demonstration State forest
- Latitude/longitude—Lat. 39.37 N.; long. 123.67 W.
- Elevation—800 ft
- Soil parent material—Undivided marine sediments
- Species studied—Coast redwood (*Sequoia sempervirens* (D. Don) Endl.)
- Duration of data collection—1970 to 1985, 1991, 1999, 2005
- Measurement interval—5 years between 1970–1985; variable thereafter

Study design—

Four stand density treatments were assigned to each of three plots in a fully randomized design. The twelve 0.4-ac plots are on an east to northeast aspect with slopes ranging from 15 to 30 degrees. Plots include a 20-ft buffer. Therefore, the measured trees were restricted to the inner 0.2 ac. Four residual stand densities were chosen for study—25, 50, 75, and 100 percent of the mean basal area as measured on the three unthinned (100-percent treatment) plots. These percentages were equivalent to 100, 200, 300, and 400 ft^2 of basal area per acre, respectively. The plots have not been rethinned.

Measurements—

All trees in the measurement plots were measured for dbh. Total height was measured on 6 to 15 randomly selected trees per plot.

Monumentation—

All measurement trees are tagged.

Publications that used data from this study—

Lindquist, J.L. 1979. Sprout regeneration of young-growth redwood: sampling methods compared. Res. Note PSW-337. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station. 8 p.

Lindquist, J.L. 2004. Growth and yield report for the Whiskey Springs Redwood Commercial Thinning Study: a twenty-nine year status report (1970–1999). California Forestry Report No. 3. Sacramento, CA: California Department of Forestry and Fire Protection. 26 p.

Oliver, W.W.; Lindquist, J.L.; Strothman(n), R.O. 1992. Stand response to thinning young-growth redwoods: implications for management. In: Proceedings, 13th annual forest vegetation management conference. Redding, CA: University of California Cooperative Extension: 33–43 p.

Oliver, W.W.; Lindquist, J.L.; Strothmann, R.O. 1994. Young-growth redwood stands respond well to various thinning intensities. Western Journal of Applied Forestry. 9(4): 106–112.

The purpose of spacing and growth studies is to determine stand growth and health resulting from various initial spacings.

II. Spacing and Growth Studies

The purpose of spacing and growth studies is to determine stand growth and health resulting from various initial spacings. After initial thinning, no subsequent attempt is made to modify density. Information about PSW spacing and growth studies is provided below (see fig. 11 for a map of the plots):

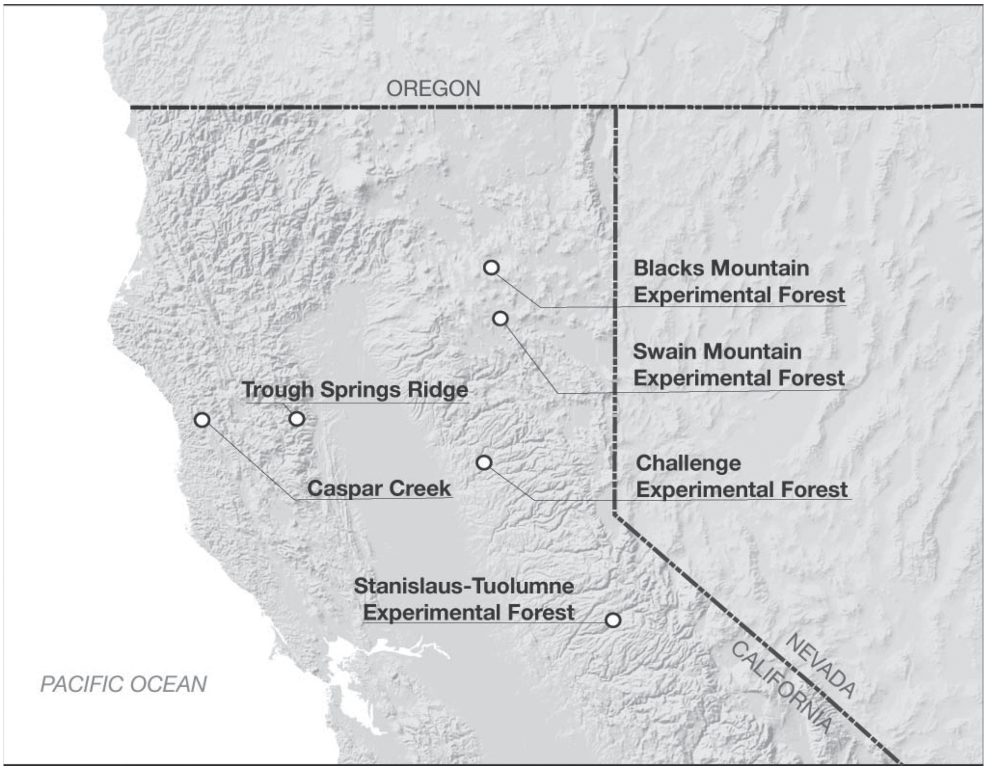


Figure 11—Spacing and growth study plots in California.

Blacks Mountain Experimental Forest (Methods-of-Harvest Cuttings Study)

History—

This massive undertaking (fig. 12) encompassed over 1,000 ac and outlived its original objective of documenting the growth and mortality after initial entry into interior pine stands. However, it became relevant again 50 years later when there was interest in maintaining and creating late-seral stand structures in interior pine stands. The study then demonstrated that the influx of a dense understory of white fir and pine could lead to the loss of the large old trees and the creation of a more uniform structure, heavy fuel loads, and an attendant high danger of wildfire. This contradicted the popular belief that, in the absence of fire, old growth would develop best in unmanaged forests.

After the last measurement in 1998–99, the study was terminated and the stands incorporated into a new study designed to test the ecological effects of contrasting stand structures, grazing, and prescribed fire on these interior pine forests (Oliver 2000).

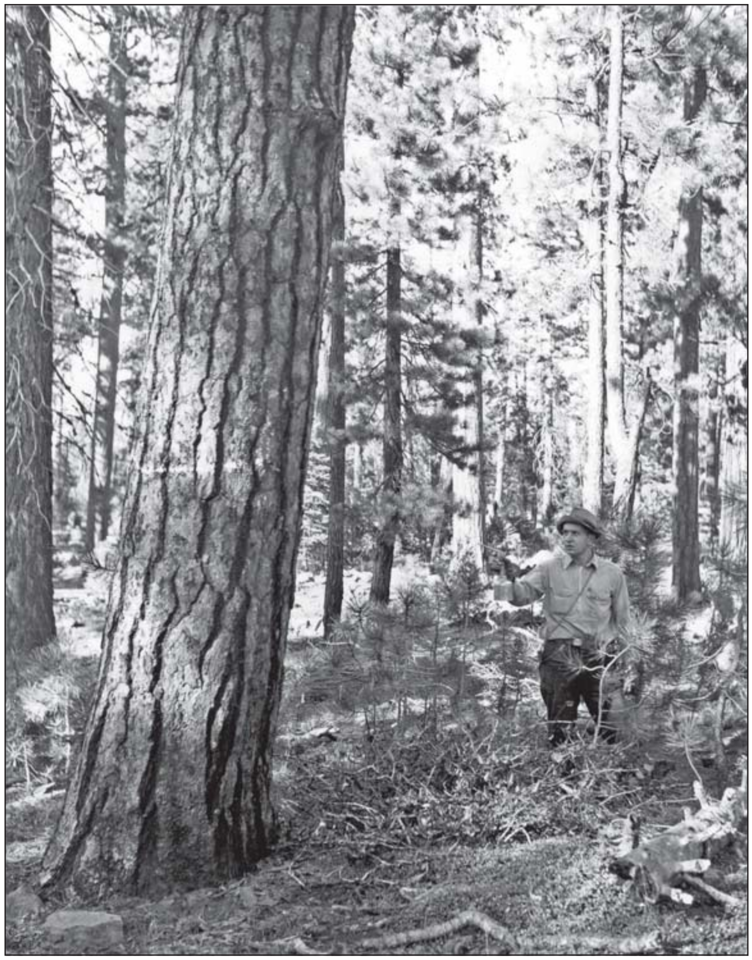


Figure 12—Marking trees in 1944 at the Blacks Mountain Experimental Forest methods-of-harvest cuttings plot.

- Location—Within the Blacks Mountain Experimental Forest
- Latitude/longitude—Lat. 41.72 N.; long. 121.13 W.
- Elevation—5,700 to 6,800 ft
- Soil parent material—Basalt
- Species studied—Ponderosa pine, Jeffrey pine, incense-cedar (*Calocedrus decurrens* (Torr.) Florin), and white fir
- Plot installation—1938-1947
- Duration of data collection—1938 to 1999
- Measurement interval—5, 10, 20, and 30 years

Study design—

Each year from 1938 to 1947, a set of four to six 20-ac rectangular plots, 660 by 1,320 ft (10 by 20 chains), was established in previously unlogged stands. Plots were buffered by a 100-ft isolation strip. Orientation of the rectangular plots was perpendicular to the contour to reduce within-plot variation caused by elevation. Treatments tested spanned the range from an unlogged control, to removal of various proportions of the merchantable volume (trees 11.6 in dbh and larger), to removal of all merchantable trees.

Measurements—

All saw-log trees were measured for dbh with a diameter tape and recorded by species at each measurement. The only exception is the unit area control treatment, which was not measured in 1998–99. During all but the last remeasurement in 1998–99, total height was ocularly estimated to the nearest 16-ft log and crown shape, foliage compliment, and Dunning Crown Class (Dunning 1928), if pine, was recorded. The location of all saw-log trees was ocularly estimated within the 66- by 66-ft grid (see Monumentation below), as was the location of ingrowth into this size class in subsequent remeasurements. Evidence of insect and disease attack was also noted.

Pole-sized trees (3.5 to 11.5 in dbh) were tallied by dbh within each 66- by 66-ft grid during the initial and 5-year remeasurements. During the last measurement, pole-sized trees were sampled by tallying by dbh class all poles within five randomly selected 66- by 660-ft strips across the short side of each plot. Seedlings were tallied by height classes within 0.01-ac circular plots.

Monumentation—

Plot corners were marked with 4- by 4-in cedar or redwood posts and plot boundaries blazed and painted in yellow. A 66- by 66-ft (1-chain) grid was surveyed within each plot and marked with 1- by 1-in redwood stakes. All trees 11.6 in dbh and larger (saw-log trees) were tagged at breast height. Ingrowth was designated by a horizontal bar on the tree tag. Smaller trees were not tagged.

Publications that used data from this study—

Dolph, K.L.; Mori, S.R.; Oliver, W.W. 1995. Height-diameter relationships for conifer species on the Blacks Mountain Experimental Forest. Res. Note PSW-418. Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. 5 p.

Dolph, K.L.; Mori, S.R.; Oliver, W.W. 1995. Long-term response of old-growth stands to varying levels of partial cutting in the eastside pine type. Western Journal of Applied Forestry. 10(3): 101–108.

Dunning, D.; Hasel, A.A. 1945. The Blacks Mountain Experimental Forest: a sustained yield experiment in ponderosa pine in northeastern California. Berkeley, CA: U.S. Department of Agriculture, Forest Service, California Forest and Range Experiment Station. 23 p.

Hasel, A.A. 1938. Methods-of-cutting demonstration plots. Berkeley, CA: U.S. Department of Agriculture, Forest Service, California Forest and Range Experiment Station. 3 p.

Eaton, C.B. 1959. Insect-caused mortality in relation to methods of cutting in ponderosa pine on the Blacks Mountain Experimental Forest. Tech. Paper 43. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station. 33 p.

Furniss, M.M.; Hallin, W.E. 1955. Development of high-risk trees in ponderosa and Jeffrey pine stands following sanitation-salvage cutting. Res. Note 94. Berkeley, CA: U.S. Department of Agriculture, Forest Service, California Forest and Range Experiment Station. 2 p.

Hasel, A.A. 1946. Logging cost as related to tree size and intensity of cutting in ponderosa pine. Journal of Forestry. 44(8): 552–560.

Hasel, A.A. 1949. Long-term silvicultural experiment on methods of cutting. Proceedings of the Berkeley symposium on mathematical statistics and probability. Berkeley, CA: University of California Press: 477–479.

Oliver, W.W. 2000. Ecological research at the Blacks Mountain Experimental Forest in northeastern California. Gen. Tech. Rep. PSW-179. Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. 66 p.

Oliver, W.W. 2002. Snag frequencies 50 years after partially cutting interior ponderosa pine stands. In: Parker, S.; Hummel, S.S., comps. Beyond 2001: a silviculture odyssey to sustaining terrestrial and aquatic ecosystems. Proceedings of 2001 national silviculture workshop. Gen. Tech. Rep. PNW-546. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station: 47–51.

O'Regan, W.G.; Arvanitis, L.G. 1967. Cost-effectiveness in forest sampling. Forest Science. 12(4): 406–414.

Salman, K.A.; Bongberg, J.W. 1942. Logging high-risk trees to control insects in the pine stands of northeastern California. Journal of Forestry. 40(7): 533–539.

Vora, R.S. 1988. A comparison of the spherical densiometer and ocular methods of estimating canopy cover. Great Basin Naturalist. 48(2): 224–227.

Vora, R.S. 1988. Potential soil compaction forty years after logging in northeastern California. Great Basin Naturalist. 48(1): 117–120.

Vora, R.S. 1988. Predicting biomass of five shrub species in northeastern California. Journal of Range Management. 41(1): 63–65.

Vora, R.S. 1988. Species frequency in relation to timber harvest methods and elevation in the pine type of northeastern California. Madrono. 35(2): 150–158.

Vora, R.S. 1993. Effects of timber harvest treatments on understory plants and herbivores in northeastern California after 40 years. Madrono. 40(1): 31–37.

Wickman, B.E.; Eaton, C.B. 1962. The effects of sanitation-salvage cutting on insect-caused pine mortality at Blacks Mountain Experimental Forest 1938–1959. Tech. Pap. 66. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station. 39 p.

Youngblood, A.; Max, T.; Coe, K. 2004. Stand structure in eastside old-growth ponderosa pine forests of Oregon and northern California. Forest Ecology and Management 199: 191–217.

Caspar Creek Precommercial Stocking Control of Coast Redwood

History—

In this study, completed in conjunction with the California Department of Forestry and Fire Protection, precommercial thinning was performed on 18 plots within a 19-year-old stand. Each plot is 0.4 ac. The 14-ac unit, which was selected for study, had previously been clearcut in 1961 as part of the Caspar Creek Cutting Trials. In 1981, five treatments were performed (100, 150, 200, 250, and 300 trees per acre plus an unthinned control). Plots were measured immediately after precommercial thinning, and again in 1986 and 1998. Because treatments were not performed subsequent to 1981, this study functions as a spacing study.

- Location—Jackson Demonstration State Forest on the west side of Road 600, south of the junctions between Road 600 and Roads 620 and 630
- Latitude/longitude—Lat. 39.38 N.; long. 123.67 W.
- Species studied—Coast redwood
- Duration of data collection—1981, 1986, 1998

Publications that used data from this study—

Lindquist, J.L. 2004. Precommercial stocking control of coast redwood: a seventeen-year status report (1981–1998). California Forestry Report No. 2. Sacramento, CA: California Department of Forestry and Fire Protection.

Challenge Experimental Forest (Initial Spacing Study)

History—

The study (fig. 13) was established within a 15-ac clearcut created especially for this study. The study has proven to be a popular stop for tours of the experimental forest because it demonstrates the dramatic effect of both intertree and shrub competition on ponderosa pine growth.

- Location—NW1/4 of the SE1/4 of sec. 29, T. 19 N., R. 7 E., MDM within the Challenge Experimental Forest
- Latitude/longitude—Lat. 39.48 N.; long. 121.22 W.
- Elevation—2,650 ft
- Soil parent material—Metavolcanics
- Species studied—Ponderosa pine
- Plot installation—1966
- Duration of data collection—1968-ongoing
- Measurement interval—1 to 5 years

Study design—

Plots are arranged in a randomized block design with split plots. Five square spacings—6, 9, 12, 15, and 18 ft—were established by planting in each of two blocks. Each spacing plot was split in half with shrubs allowed to develop naturally on one half and shrubs removed on the other half. Shrubs were removed by hand grubbing for the first 5 years and then periodically killed by herbicides, thereafter. The spacing plots are buffered by three rows of trees or a minimum of 21 ft. The interior division between subplots is buffered by two rows of trees. All subplots contain 12 measurement trees regardless of spacing. Therefore, the size of subplots with buffer differs by spacing from 0.11 ac for the 6-ft spacing to 0.36 ac for the 18-ft spacing.

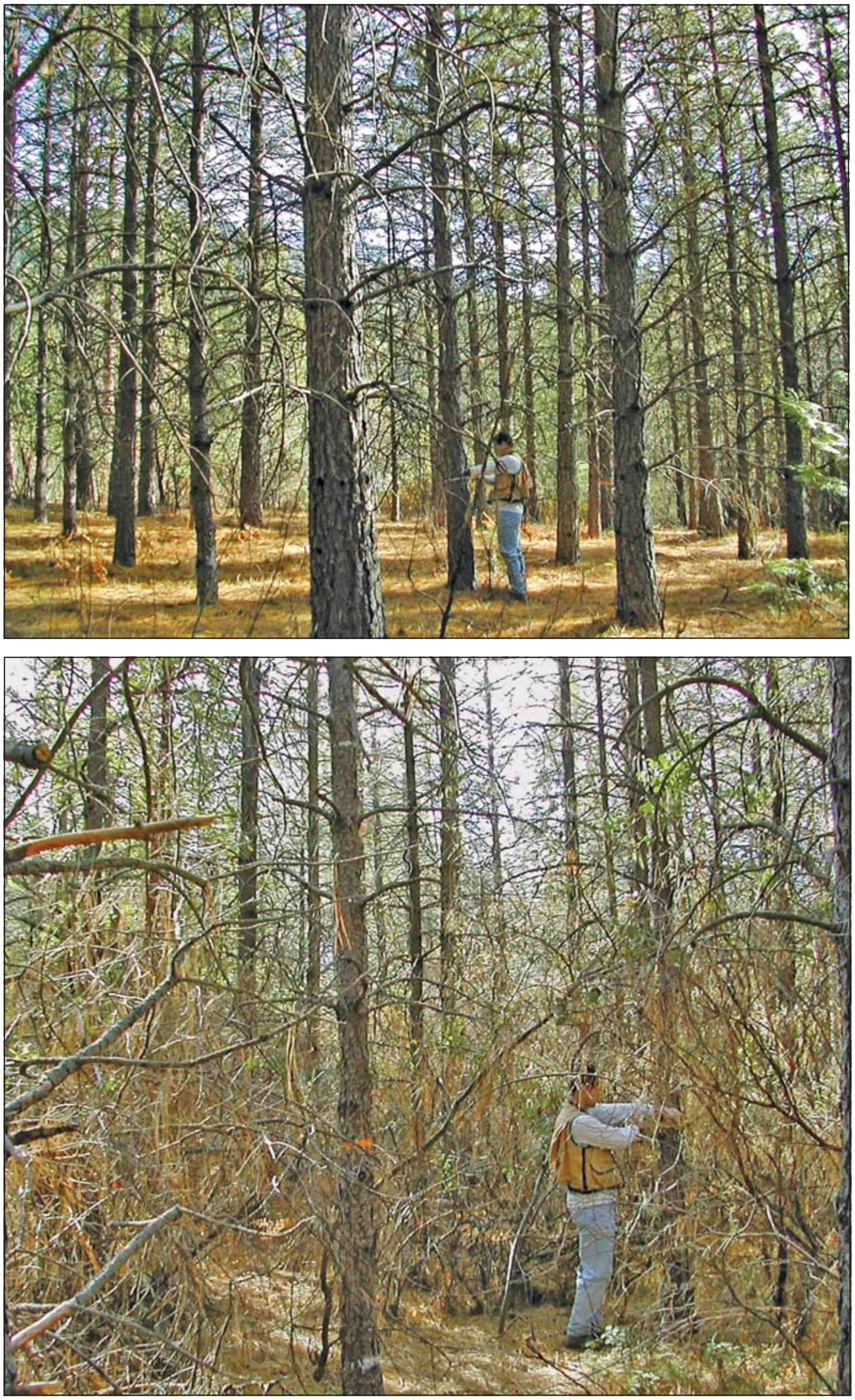
Measurements—

All measurement trees were measured for dbh, total height, height to live crown, and crown width. Evidence of insect and disease attack was also noted. Taped measurements were taken at 1 ft and at the base of the live crown on all measurement trees to determine stem volume during several remeasurements.

Monumentation—

Plot corners are monumented by metal fenceposts. Interior subplot corners are monumented by short metal stakes. All measurement trees are numbered by a tag attached to a wire stake in the ground adjacent to the tree. Diameter at breast height is indicated by a yellow band.

A



B

Figure 13—Challenge Initial Spacing Study. Trees in this plot are spaced 12 ft apart and are (A) free of competing shrubs or (B) in competition with shrubs. These photographs were taken in 2002.

Publications that used data from this study—

McDonald, P.M.; Oliver, W.W. 1984. Woody shrubs retard growth of ponderosa pine seedlings and saplings. In: Proceedings, 5th annual forest vegetation management conference. Redding, CA: University of California Cooperative Extension: 65–89.

Oliver, W.W. 1974. Moisture stress related to spacing and brush competition in a ponderosa pine plantation [Abstract]. In: Proceedings, 3rd North American forest biology workshop. Fort Collins, CO: College of Forestry and Natural Resources, Colorado State University: 378–379.

Oliver, W.W. 1980. Early response of ponderosa pine to spacing and brush: observations on a 12-year-old plantation. Res. Note PSW-341. Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. 7 p.

Oliver, W.W. 1990. Brush competition retards early stand development of planted ponderosa pine: update on a 24-year study. In: Proceedings, 11th annual forest vegetation management conference. Redding, CA: University of California Cooperative Extension: 107–113.

Oliver, W.W. 1990. Spacing and shrub competition influence 20-year development of planted ponderosa pine. Western Journal of Applied Forestry. 5(3): 79–82.

Oliver, W.W. 1995. Is self-thinning of ponderosa pine ruled by *Dendroctonus* bark beetles? In: Eskew, L.G., comp. Forest health through silviculture. Proceedings of the 1995 national silviculture workshop. Gen. Tech. Rep. RM-267. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 213–218.

Oliver, W.W.; Ferrell, G.T.; Tappeiner, J.C. 1996. Density management of Sierra Nevada forests. In: Sierra Nevada ecosystem project: final report to Congress. Vol. III, assessments, commissioned reports, and background information. Davis, CA: University of California, Center for Water and Wildland Resources: 491–500.

Oliver, W.W.; Uzoh, F.C.C. 1997. Maximum stand densities for ponderosa pine and red and white fir in northern California. In: Proceedings, 18th annual forest vegetation management conference. Redding, CA: University of California Cooperative Extension: 57-65.

Powers, R.F.; Oliver, W.W. 1984. Ponderosa pine plantation growth in northern California…brush competition and response to release. In: Summaries of the proceedings of the 1984 western forestry conference. Sacramento, CA: Western Forestry and Conservation Association: 122–125.

Zhang, J.W; Oliver, W.W.; Busse, M.D. 2006. Growth and development of ponderosa pine on sites of contrasting productivities: relative importance of stand density and shrub competition effects. Canadian Journal of Forest Research. 36: 2426–2438.

Stanislaus-Tuolumne Experimental Forest (Methods-of-Harvest Cuttings Study)

History—

The initial objective of this Methods of Cutting study (fig. 14) was to “determine the rate of restocking after a light, a moderate, and a heavy selection cutting” (Hasel et al. 1934). Duncan Dunning, the U.S. Forest Service researcher who was the lead figure behind this effort, was concerned with the observation that many stands formerly containing large valuable pines were regenerating predominantly to fir and incense-cedar after logging. The important role of recurring low-intensity fire in thinning out the young firs and cedars was not fully appreciated at that time (while fires were being suppressed by 1929, and the last major fire in this area occurred about 1890; composition of the original stand was therefore surely strongly influenced by frequent fire). As this pattern of stand succession after logging in the absence of fire became better understood (Fowells and Schubert 1951), interest in remeasuring the plots waned. However, few permanently monumented plots of this age and size with such a wealth of data associated with them exist in an undisturbed state. Because of this, their value has increased with time.

- Location—Within the Stanislaus-Tuolumne Experimental Forest
- Latitude/longitude—Lat. 38.18 N.; long. 120.00 W.
- Elevation—5,700 to 5,900 ft
- Soil parent material—Biotite-hornblende granodiorite of volcaniclastic origin
- Species studied—sugar pine (*Pinus lambertiana* Dougl.), white fir, incense-cedar, ponderosa pine, and Jeffrey pine
- Plot installation—1929
- Duration of data collection—1929 to 1947, 2007-ongoing

Measurement interval—

5 years (1934 and 1939) for trees, yearly (1929–38) and then again in 1942 and 1947 for tree seedlings and understory vegetation. Measurement is beginning again in 2007 with remeasurement expected every 10 years.

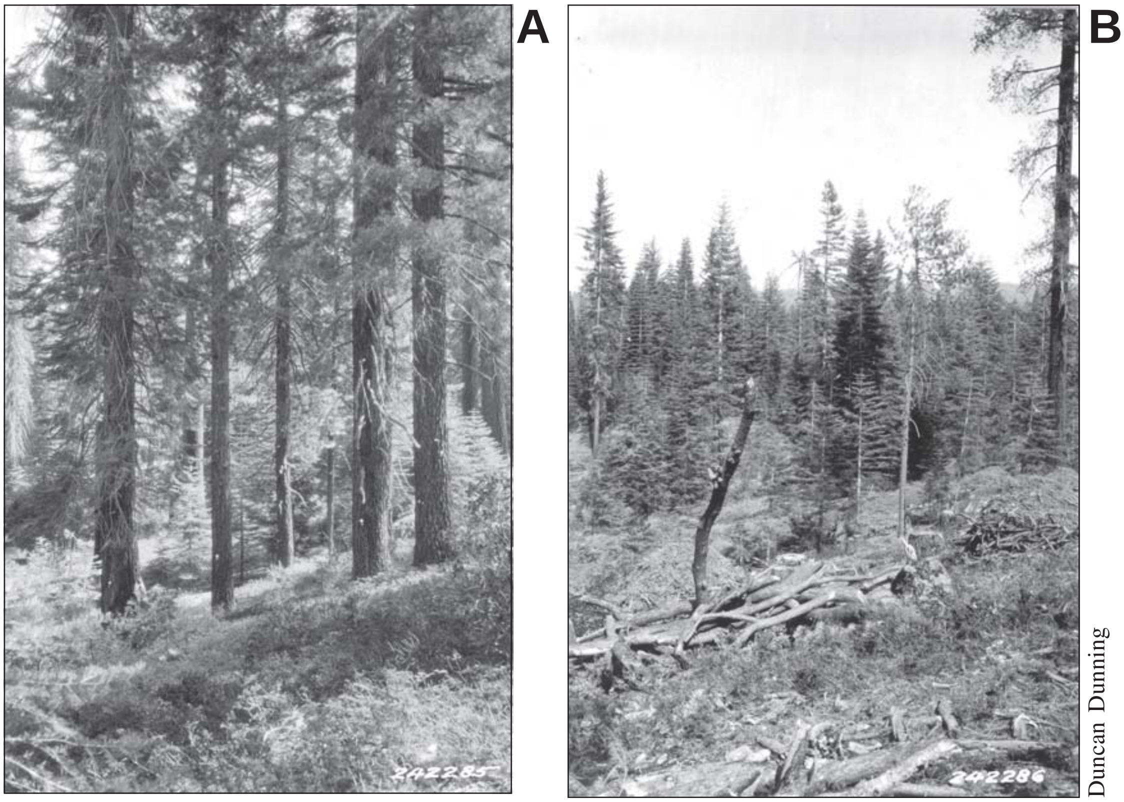


Figure 14—View from photo point within “Method of Cutting” plot 11 on the Stanislaus-Tuolumne Experimental Forest. This plot was harvested using a system of heavy cutting, replicating the practice of removing all merchantable timber and abandoning the land, common in the private sector at that time. (A) Before logging, in May 1929; (B) After logging, in October 1929.

Study design—

Three approximately 10-ac rectangular “Methods of Cutting” (MC) plots, were established in spring 1929 within the boundaries of a larger study to evaluate the economics of different logging and milling practices. The stand in which the plots were placed was previously unlogged old-growth mixed conifer with a relatively high proportion of sugar pine on excellent site quality land. The three logging treatments were compared. The MC plot 9 was marked according to standard Forest Service practices, which was a sanitation-salvage improvement cutting of all species, focusing on release of pines, spacing of seed trees and improved growth of the residual stand. The MC plot 10 was logged according to an economic selection system proposed by a firm of consulting foresters. The objective was to remove high-value trees (mainly larger defect-free pines), without improvement cutting for sanitation salvage, or growth of the residual stand. The MC plot 11 was marked for a heavy cut by the lead faller for the Pickering Lumber Company, with the objective of giving the highest return per acre to the landowner, who was then to abandon the land. With this treatment, all merchantable trees were cut.

The MC plots 9 and 11 were each 594 by 792 ft (9 chains by 12 chains), while MC plot 10 was 528 by 792 ft (8 chains by 12 chains). Plots were orientated perpendicular to the contour on the same north-northwest facing slope to reduce among-plot variation caused by elevation. Logging was done in June and July 1929.

Nine additional methods of cutting plots were established nearby on Stanislaus National Forest lands during the 1920s, but only the three listed here are known to be undisturbed since initial treatment entry.

Measurements—

Before logging, all trees with a diameter greater than 3.6 in dbh were mapped with a transit and chain and labeled with a uniquely numbered metal tag. Diameter at breast height and height were measured and species noted for all trees. Boundaries of brush, logs, and rock outcrops were also drawn on the maps. Three transects (one per plot) were established. Along each transect, there were 100 quadrats, each a milacre (6.6 by 6.6 ft) in size, within which shrubs and tree seedlings were mapped in greater detail. Height and species of each tree seedling were noted. On every 10th quadrat, herbaceous vegetation was also quantified (for a total of 10 quadrats per transect). After logging, plots were remapped to show damage and tags applied to all trees greater than 3.6 in dbh.

Trees were remeasured in 1934 and again in 1939. As saplings reached the 3.6 in threshold, they were tagged and measured as well. Black and white photographs were taken from points noted on the maps prior to logging, and photos were taken of some points again after logging. Vegetation within the milacre quadrats was evaluated yearly and remapped periodically through 1947. The three methods of cutting plots and associated data were rediscovered in 2006. Original plot maps were digitized, and remapping of trees was completed in 2008. Many of the trees still contain their original numbered tags.

Monumentation—

Plot corners are marked with pieces of metal pipe pounded into the ground. A 66- by 66-ft (1-chain) grid was surveyed within each plot, and many of the grid points along the outer boundaries are marked with the same metal pipe. All four corners of the 300 milacre quadrats are also marked with metal pipe, although a number of these corner posts have been lost over time.

Publications that used data from this study—

Fowells, H.A.; Schubert, G.H. 1951. Natural reproduction in certain cutover pine-fir stands of California. Journal of Forestry. 49: 192–196.

Fowells, H.A.; Schubert, G.H. 1956. Seed crops of forest trees in the pine region of California. Tech. Bull. 1150. Washington, DC: U.S. Department of Agriculture. 47 p.

Hasel, A.A.; Wohletz, E.; Tallmon, W.B. 1934. Methods-of-cutting, California Forest and Range Experiment Station, Stanislaus Branch, Plots 9, 10, 11, Progress Report. 137 p. Unpublished report. On file with: USDA Forest Service, Pacific Southwest Research Station, Silviculture Laboratory, 3644 Avtech Parkway, Redding, CA 96002.

Wagener, W.W. 1961. Past fire incidence in Sierra Nevada forests. Journal of Forestry. 59: 739–748.

Swain Mountain Experimental Forest (Initial Spacing Study)

History—

This extremely dense sapling stand, averaging 9,700 stems per acre, was released from a ragged overstory of red fir 12 years before the study was installed. Consequently, thinning treatments were performed in stages. All plots were thinned in 1972 to 20 ft^2 per tree. The 40 ft^2 treatment was rethinned to its designed spacing in 1976, and the three wider spacings were established in 1980 (fig. 15).

- Location—The NE1/4 of sec. 32, T. 30. N., R. 8 E. MDM within the Swain Mountain Experimental Forest
- Latitude/longitude—Lat. 40.43 N.; long. 121.10 W.
- Elevation—6,700 ft
- Soil parent material—Basalt
- Species studied—Red fir
- Plot installation—1972
- Duration of data collection—1972 to 2002
- Measurement interval—4 to 6 years

Study design—

The ten 0.2-ac plots are arranged in a fully randomized design with two replications on a northeast-facing slope. Five spacings were assigned based on areas per tree of 20, 40, 80, 160, and 320 ft^2. The plots are buffered with a 20-ft isolation strip.

Jianwei Zhang

Figure 15—Swain Mountain Experimental Forest Initial Spacing Study plot in 2005 with spacing of 80 ft^2/tree.

Measurements—

All measurement trees were measured for dbh. Evidence of insect and disease attack was also noted. A systematic sample of 20 percent of the trees was measured for total height, height to live crown, and crown width. During the initial measurement in 1972, stem diameter at 1ft was measured to determine stem volume.

Monumentation—

Plot corners were monumented with short, metal stakes. Trees just inside the boundary are banded in yellow. All measurement trees are identified by a numbered metal tag wired to a branch near breast height and have a spot of paint at breast height, although they are not banded.

Publications that used data from this study—

Oliver, W.W. 1986. Growth of California red fir advance regeneration after overstory removal and thinning. Res. Pap. PSW-180. Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. 6 p.

Zhang, J.W.; Oliver, W.W. 2006. Stand structure and growth of *Abies magnifica* responded to five thinning levels in northeastern California, USA. Forest Ecology and Management. 223: 275–283.

Trough Springs Ridge (Initial Spacing Study)

History—

This study (fig. 16) was established in an 11-year-old plantation that originated after a fire. The soil, determined to be a shallow form of the Sheetiron Series prefire, was degraded to a Maymen Series when much of the "A" horizon was removed in clearing the site for planting. The Maymen Series is generally considered to support only shrubs. The study was originally designed to be an installation in the West-Wide Levels-of-Growing-Stock study for even-aged ponderosa pine. Thus, the tree spacings are equivalent to GSLs prescribed in Myers' (1967) study plan. However, after the 5-year remeasurement, it was determined that tree stand density had no influence on tree growth because of the dense shrub understory. Therefore, the field design was altered to investigate the interrelationships of tree spacing and shrub density on growth of ponderosa pine on a site of low productivity.

- Location—E1/2 of the W1/2 of sec. 32, T. 17 N., R. 7 W., MDM within the Stonyford Ranger District, Mendocino National Forest
- Latitude/longitude—Lat. 39.28 N.; long. 122.67 W.
- Elevation—4,000 ft
- Soil parent material—Metasediments
- Species studied—Ponderosa pine
- Plot installation—1970
- Duration of data collection—1970-ongoing
- Measurement interval—5 to 9 years

Study design—

Fifteen 0.25-ac plots are arranged on various aspects along a narrow ridge in a randomized block design with split plots. Plots were grouped into three blocks on the basis of small differences in site quality. Five spacings are under test, each replicated three times. Each spacing plot is split into three subplots. All shrubs were allowed to develop naturally on one subplot, half were removed in the middle subplot, and all were removed by cutting at ground line in the other outer subplot. The nonsprouting forms of *Arctostaphylos* sp. made retreatment unnecessary. The spacing plots are buffered by a 20-ft isolation strip. The interior divisions between the subplots are not buffered.

Figure 16—Trough Springs Ridge plot initial spacing study plot in 1977 with competing shrubs.

Measurements—

All measurement trees were measured for dbh, and evidence of insect and disease attack were noted. A systematic sample of 20 percent of the trees was measured for total height, height to live crown, and crown width until 1996. Only total height was sampled in 2005. A probability-proportional-to-size sample of six trees per subplot was selected for taped measurements of the stem at 1 ft and at the base of the live crown to determine stem volume during the 1970, 1980, and 1985 measurements.

Monumentation—

Metal fenceposts originally marked the corners of the spacing plots and short metal stakes marked the subplot corners. All trees are tagged and banded in yellow at breast height. Trees too small to accept a nail have tags wired to a branch near breast height.

Publications that used data from this study—

McDonald, P.M.; Oliver, W.W. 1984. Woody shrubs retard growth of ponderosa pine seedlings and saplings. In: Proceedings, 5th Annual forest vegetation management conference. Redding, CA: University of California Cooperative Extension: 65–89.

Oliver, W.W. 1984. Brush reduces growth of thinned ponderosa pine in northern California. Res. Pap. PSW-172. Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. 7 p.

Oliver, W.W.; Ferrell, G.T.; Tappeiner, J.C. 1996. Density management of Sierra Nevada forests. In: Sierra Nevada ecosystem project: final report to Congress. Vol. III, assessments, commissioned reports, and background Information. Davis, CA: University of California, Center for Water and Wildland Resources: 491–500.

Powers, R.F.; Oliver, W.W. 1984. Ponderosa pine plantation growth in northern California: brush competition and response to release. In: Summaries of the proceedings of the 1984 Western Forestry Conference. Sacramento, CA: Western Forestry and Conservation Association: 122–125.

Zhang, J.W.; Oliver, W.W.; Busse, M.D. 2006. Growth and development of ponderosa pine on sites of contrasting productivities: relative importance of stand density and shrub competition effects. Canadian Journal of Forest Research. 36: 2426–2438.

The Garden of Eden experiment was established to determine how combinations of intensive silviculture affect the productivity of ponderosa pine plantations.

III. Garden of Eden Studies

The Garden of Eden experiment was established to determine how combinations of intensive silviculture affect the productivity of ponderosa pine plantations. The experiment centers on lands owned by industrial forestry cooperators throughout northern California and across an extreme range of site qualities. Originally, nine installations were established between 1986 and 1988. Of these, six remain today (fig. 17). Each installation was prepared carefully and planted with families of ponderosa pine recommended by the Forest Service, Pacific Southwest Region geneticist for superior growth performance for that elevation and seed zone. Installations were remeasured regularly (fig. 18). To ensure nursery uniformity, seedlings were raised for planting at the PSW's Institute of Forest Genetics at Placerville.

Treatment plots measuring 0.11 ac each (64 by 72 ft) are arranged in four columns and six rows, with an identical arrangement at all installations (fig. 19). Treatments were applied in a completely randomized design of three replications each of eight treatments. Unless otherwise noted, all treatments were the same at each installation. Treatments consisted of a control ("C" no further treatment beyond planting), herbicide ("H" applied annually to eliminate any competing vegetation other than planted trees), insecticide ("I" applied annually as a spray of systemic chemicals), and fertilization ("F" a mixture of macro- and micronutrients

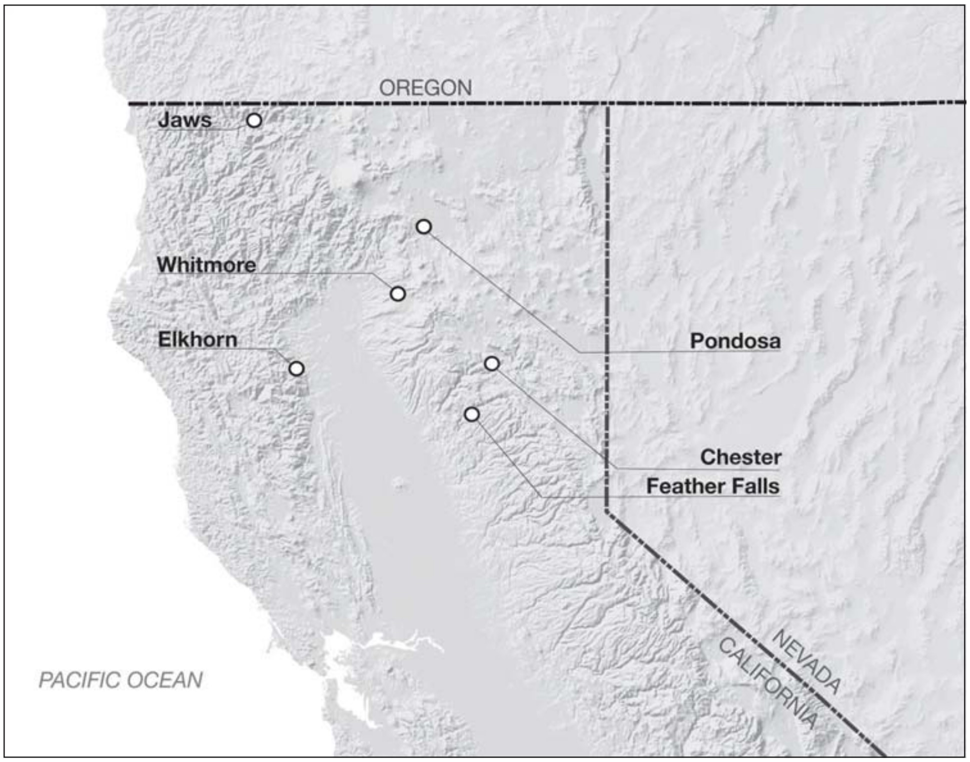


Figure 17—Garden of Eden plots.


A

Bob Powers

B

Bob Powers

Figure 18—Elkhorn Garden of Eden plantation, the poorest site within the Garden of Eden study. (A) Control plot in 1997 when the plantation was 10 years old. Note abundance of competing vegetation. (B) Full treatment plot in 1997. Note lack of competing vegetation.

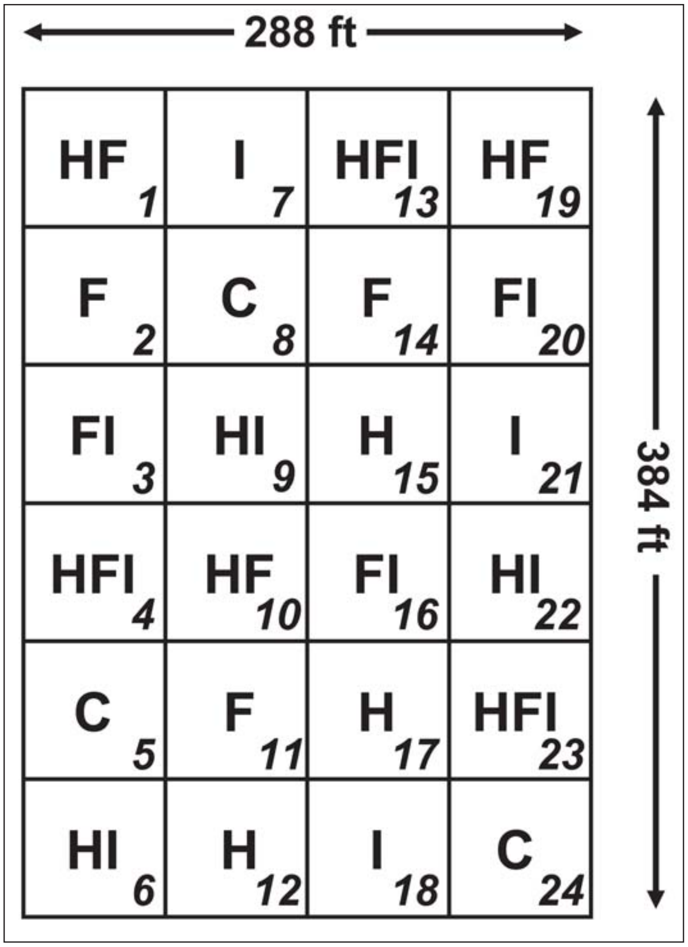


Figure 19—Standard layout of 24 treatment plots in the Garden of Eden experiment. Plot numbers are tagged on wooden orange stakes in the lower right corner. C = control, H = herbicide, F = fertilizer, I = insecticide. Each of the 24 treatment plots measures 64 by 72 ft.

applied biennially at a geometric rate). Applied in all factorial combinations, this resulted in eight treatments and 24 treatment plots per installation (fig. 19). Herbicides (primarily glyphosate) were applied to "H" plots by directed spray in consecutive springs until all competing vegetation was eliminated (usually by 6 years). Insecticides (acephate and dimethoate) were applied each spring by backpack sprayer directly to tree foliage in the "I" treatments to the point of crown drip. This was discontinued after the 8th year when no insect problems had been observed in any treatments. Fertilizers (nitrogen, phosphorus, potassium, calcium, magnesium, sulfur, zinc, copper, boron) were applied at planting in holes at four sides of each tree in the "F" treatment at a distance of about two-thirds the height of the tree. Preweighed fertilizers were applied prior to growth in the spring in years 1, 3, 5,

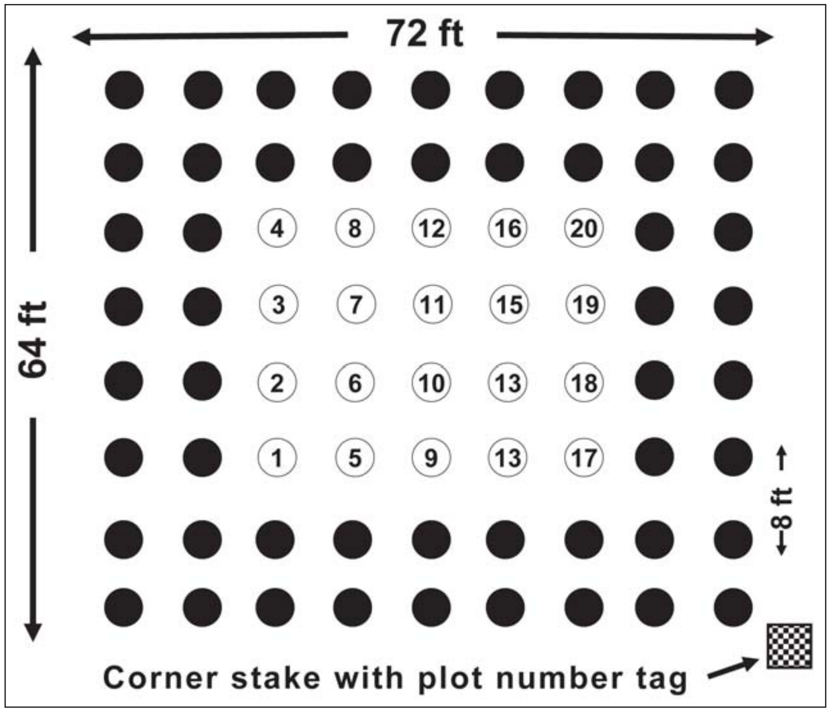


Figure 20—Standard layout of a treatment plot in the Garden of Eden experiment. Plot number is on a metal tag fixed to an orange, wooden stake in the lower right corner relative to plot position in figure 19. Each treatment plot measures 64 by 72 ft. Measurement trees (white circles) in five columns of four rows, with tree "1" always in lower left corner. Two rows of buffer trees shown as dark circles. Trees planted on 8- by 8-ft spacing.

and 7. Rates increased in proportion to anticipated growth. In year 7, fertilizers were applied in bands between rows of trees.

Trees were planted in an 8- by 8-ft square spacing of 9 columns and 8 rows (72 trees per plot) (fig. 20). Measurement trees consisted of the 20 innermost trees, separated from the treatment plot boundary by two rows of trees (16 ft). As seen in figure 20, the two outer rows of trees serve as a buffer. Tree dimensions (dbh, height, height to base of live crown), foliar samples (current and 1-year-old needles), and understory cover (percentage of cover and height by species) were measured at the end of every second growing season through year 10, and less frequently thereafter. Early results have been published in the following references.

Publications that used data from the Garden of Eden study—

Busse, M.D.; Fiddler G.O.; Ratcliff, A.W. 2004. Ectomycorrhizal formation in herbicide-treated soils of differing clay and organic matter content. Water, Air, and Soil Pollution. 152: 23–34.

Busse, M.D.; Rappaport, N.G.; Powers, R.F. 2000. Tolerance of soil organisms to herbicide applications in ponderosa pine plantations: Initial findings. In: Cooper, S.L., comp. Reforestation for the New Millemium: back to our roots. Proceedings of the 21st annual forest vegetation management conference, Redding, CA: University of California Cooperative Extension: 33–38.

Busse, M.D.; Rappaport, N.G.; Powers, R.F. 2001. Hexazinone effects on soil biota and processes: initial findings. In: Cooper, S.L., comp. Proceedings, 22nd annual forest vegetation management conference. Redding, CA: University of California Cooperative Extension: 66–72.

Busse, M.D.; Ratcliff, A.W.; Shestak, C.J.; Powers, R.F. 2000. Non-target effects of glyphosate on soil microbes. In: Proceedings, California Weed Science Society. California Weed Science Society. 52: 146–150.

Busse, M.D.; Ratcliff, A.W.; Shestak, C.J.; Powers, R.F. 2001. Glyphosate toxicity and the effects of long-term vegetation control on soil microbial communities. Soil Biology and Biochemistry. 33: 1777–1789.

Hayes, J.P.; Schoenholtz, S.H.; Hartley, M.J.; Murphy, G.; Powers, R.F.; Berg, D.; Radosevich, S.R. 2005. Environmental consequences of intensively managed forest plantations in the Pacific Northwest. Journal of Forestry. 103(2): 83–87.

McFarlane, K.J.; Schoenholtz, S.H.; Powers, R.F. [In press]. Plantation management intensity affects belowground carbon and nitrogen storage in northern California. Manuscript accepted. Soil Science Society of America Journal.

Mahoney, R.L.; Powers, R.F. 2005. Silvicultural decisions X: Is there a future for growing and processing timber in the inland Northwest? Woodland Notes, University of Idaho, Moscow. 15(2): 2, 4.

Powers, R.F. 1999. The “Garden of Eden” experiment: assessing the potential productivity of planted ponderosa pine. In: Ramsay, C., comp. Vegetation management in the era of threatened and endangered species. Proceedings of the 3rd annual PNW-IVMA forestry and rights-of-way conference. Portland, OR: Pacific Northwest Integrated Vegetation Management Association: 40–45.

Powers, R.F. 1999. On the sustainability productivity of planted forests. New Forests. 17: 253–306.

Powers, R.F. 2000. Balderston plantation revisited: Does vegetation control or fertilization really matter? In: Fiddler, G.O., comp. Progress report 2000. Sierra Cascade Intensive Forest Management Research Cooperative Newsletter Series Rep. No. 1. Davis, CA: University of California: 9–15.

Powers, R.F. 2000. The role of planted forests in a "green certified" century. In: Cooper, S.L., comp. Reforestation for the New Millennium: back to our roots. Proceedings, 21st forest vegetation management conference. Redding, CA: University of California Cooperative Extension: 1–17.

Powers, R.F. 2001. Further analyses from Balderston Plantation. In: Fiddler, G.O., comp. Progress Report 2001. Sierra Cascade Intensive Forest Management Research Cooperative Series Rep. No. 2. Davis, CA: University of California: 8–10.

Powers, R.F. 2003. World trends in forests, forest use, wood supply. The irony of California forestry. The challenge to our profession. In: Cooper, S.L., comp. Proceedings, 24th annual forest vegetation management conference. Redding, CA: University of California Cooperative Extension: 1–16.

Powers, R.F.; Ferrell, G.T. 1995. Plantation development as constrained by moisture, nutrition, and insects: The "Garden of Eden" study. In: Gaskin, R.E.; Zabkiewicz, J.A., comp. Proceedings, 2nd international conference on forest vegetation management. Forest Research Institute Bulletin, 192. Rotorua, New Zealand: Forest Research Institute: 92–94.

Powers, R.F.; Ferrell, G.T. 1996. The "Garden of Eden" study revisited: findings at eight years. In: Landram, M., comp. Proceedings, 17th annual forest vegetation management conference. Redding, CA: University of California Cooperative Extension: 8–31.

Powers, R.F.; Ferrell, G.T. 1996. Moisture, nutrient, and insect constraints on plantation growth: The "Garden of Eden" experiment. New Zealand Journal of Forestry Science. 26: 126–144.

Powers, R.F.; Koerber, T.W.; Ferrell, G.T. 1992. The Garden of Eden experiment: four-year growth of ponderosa pine plantations. In: Proceedings, 13th annual forest vegetation management conference. Redding, CA: University of California Cooperative Extension: 46–63.

Powers, R.F.; Reynolds, P.E. 1999. Ten-year responses of ponderosa pine plantations to repeated vegetation and nutrient control along an environmental gradient. Canadian Journal of Forest Research. 29: 1027–1038.

Powers, R.F.; Reynolds, P.E. 2000. Intensive management of ponderosa pine plantations: sustainable productivity for the 21st century. Journal of Sustainable Forestry. 10(3-4): 249–255.

Powers, R.F.; Spear, T. 1997. Weed competition and plantation management: The "Garden of Eden" experiment. In: Weed science. In search of excellence. Proceedings, 49th annual conference of the California Weed Science Society. Fremont, CA: California Weed Science Society: 118–130.

Powers, R.F.; Young, D.H.; Fiddler, G.O.; Spear, T.H. 2005. Balderston plantation revisited: a tale of two sites 25 years after early treatments. In: Cooper, S.L., comp. Where we've been, where we are, and where we're going. Proceedings, 25th forest vegetation management conference. Redding, CA: University of California Cooperative Extension: 61–72.

Reynolds, P.E.; Powers, R.F. 2000. Gas exchange for managed ponderosa pine stands positioned along a climatic gradient. Journal of Sustainable Forestry. 10(3-4): 257–265.

Chester Garden of Eden Plantation

History—

The site is in the rain shadow of the southern Cascade Mountains. It was originally railroad logged by the Red River Lumber Company in the early 1900s. The site eventually reverted to a brushfield comprised largely of greenleaf manzanita (*Arctostaphylos patula*) and snowbrush (*Ceanothus velutinus*). Brush was removed by tractor and brush rake in 1986 and piled offsite. It received one hexazinone application to temporarily inhibit resprouting brush. A wire fence was constructed to reduce animal damage to young seedlings (primarily by porcupines). The HI and HFI plots were thinned from below in August 2003, and samples were taken for biomass analysis.

- Location—SE1/4 of SE1/4 sec. 5, T. 28 N., R 8 E., MDM on land managed by Roseburg Resources, Weed, California
- Latitude/longitude—Lat. 40.30 N.; long. 121.10 W.
- Elevation—4,805 ft
- Soil parent material—Andesite and volcanic ash
- Species studied—Ponderosa pine
- Plot installation—1987
- Duration of data collection—1987-ongoing
- Measurement interval—2 years, changing to 5 years by age 10

Study design—

A completely randomized design with three replications was used. All measurement plots of 20 original trees are buffered with two rows of planted trees.

Measurements—

All trees within the plots were measured using diameter tapes (nearest 0.1 in) and height poles (nearest 0.1 ft). Stem deformities and evidence of insect and disease attack were also noted. Total height and height to live crown were measured on all trees, as well as crown diameter at the widest point (mean of two right-angle measurements).

Monumentation—

Treatment plot corners are numbered orange stakes, and measurement plot corners are white stakes. However, some of the stakes may be missing. All measurement trees are painted at 2 in below breast height.

Elkhorn Garden of Eden Plantation

History—

The site is on a north-northeastern exposure at the eastern edge of the California Coast Ranges. The area supported mature, mixed-conifer forest prior to 1977, and had received sanitation harvests in 1965 and again in 1973. The site was burned in a severe wildfire in August, 1977. It was salvage logged immediately after the fire and again in 1983 following wind damage to residual trees. Ponderosa pine was planted in 1979 and 1980.

The site was prepared by D-6 tractor and brush rake in July 1987 to create a planting area for this study, and vegetation was piled along the edge of a 4-ac clearing. Planting spots were surveyed using transit and tape in early spring 1987 and bare root pine of superior families were planted in March 1988. Survival on F and FI treatments was poor, ranging between 0 and 70 percent. Of this, some was associated with lower slope plots that included old skid trails or landings. Survival on remaining plots ranged between 60 and 100 percent.

- Location—NW1/4 of sec. 26, T. 26 N., R. 8 W., MDM on land managed by Crane Mills, Corning, California
- Latitude/longitude—Lat. 40.08 N.; long. 122.75 W.
- Elevation—5,050 ft
- Soil parent material—Metamorphosed metasediments
- Species studied—Ponderosa pine
- Plot installation—1988

- Duration of data collection—1988-ongoing
- Measurement interval—2 years, changing to 5 years after age 10

Study design—
A completely randomized design with three replications was used. All measurement plots of 20 original trees are buffered with two rows of planted trees.

Measurements—
All trees within the plots were measured using diameter tapes (nearest 0.1 in) and height poles (nearest 0.1 ft). Stem deformities and evidence of insect and disease attack were also noted. Total height and height to live crown were measured on all trees, as well as crown diameter at the widest point (mean of two right-angle measurements). Forest floor samples and soil cores, to a 4-ft depth, were collected from C, F, H, and HF plots in 2006 for mass and chemical analyses. All vegetation was sampled in spring 2008 for complete analysis of above- and belowground biomass.

Monumentation—
Treatment plot corners are numbered orange stakes, and measurement plot corners are white stakes. However, some of the stakes may be missing.

Feather Falls Garden of Eden Plantation

History—
The site is on a western slope of the northern Sierra Nevada in an area supporting mixed-conifer forest. The brushy understory and overstory of tanoak (*Lithocarpus* sp.) were cleared by the Louisiana-Pacific Corporation for this study. Eventually, the land was purchased by the present owner, Sierra Pacific. The HI and HFI plots were thinned from below in March 1996, and samples were taken for biomass analysis.

- Location—SW1/4 sec. 4, T. 20 N., R. 7 E., MDM on land managed by Sierra Pacific Industries
- Latitude/longitude—Lat. 39.62 N.; long. 121.20 W.
- Elevation—4,080 ft
- Soil parent material—Basalt
- Species studied—Ponderosa pine
- Plot installation—1988
- Duration of data collection—1988-ongoing
- Measurement interval—2 years, changing to 5 years by age 10

Study design—

A completely randomized design with three replications was used. All measurement plots of 20 original trees are buffered with two rows of planted trees.

Measurements—

All trees within the plots were measured using diameter tapes (nearest 0.1 in) and height poles (nearest 0.1 ft). Stem deformities and evidence of insect and disease attack were also noted. Total height and height to live crown were measured on all trees, as well as crown diameter at the widest point (mean of two right-angle measurements). Forest floor samples and soil cores, to a 4-ft depth, were collected from C, F, H, and HF plots in 2006 for mass and chemical analyses. All vegetation was sampled in spring 2008 for complete analysis of above- and belowground biomass.

Monumentation—

Treatment plot corners are numbered orange stakes, and measurement plot corners are white stakes. However, some of the stakes may be missing. All measurement trees are painted at 2 in below breast height.

Jaws Garden of Eden Plantation

History—

The site faces south toward the Klamath River in the Klamath Mountains. The HI and HFI plots were thinned from below in August 1997, and samples were taken for biomass analysis.

- Location—NW1/4 sec. 31, T. 47 N., R. 10 W. MDM on land managed by Fruit Growers Supply, Hilt, California
- Latitude/longitude—Lat. 41.89 N.; long. 123.05 W.
- Elevation—3,300 ft
- Soil parent material—Metamorphosed sediments
- Species studied—Ponderosa pine
- Plot installation—1988
- Duration of data collection—1988-ongoing
- Measurement interval—2 years, changing to 5 years by age 10

Study design—

A completely randomized design with three replications was used. All measurement plots of 20 original trees are buffered with two rows of planted trees.

Measurements—
All trees within the plots were measured using diameter tapes (nearest 0.1 in) and height poles (nearest 0.1 ft). Stem deformities and evidence of insect and disease attack were also noted. Total height and height to live crown were measured on all trees, as well as crown diameter at the widest point (mean of two right-angle measurements).

Monumentation—
Treatment plot corners are numbered orange stakes, and measurement plot corners are white stakes. However, some of the stakes may be missing. All measurement trees are painted at 2 in below breast height.

Pondosa Garden of Eden Plantation

History—
The site is in the southern Cascade Mountains. The original forest was mixed conifer with a heavy component of ponderosa pine. This was consumed in the Pondosa Fire of 1977. The site was salvage logged and planted with ponderosa pine. Part of the area was cleared by brush rake for the Garden of Eden study. The HI and HFI plots were thinned from below in August 2003, and samples were taken for biomass analysis.

- Location—SW1/4 of NE1/4 sec. 21, T. 39 N., R. 3 E., MDM on land managed by Roseburg Resources, Weed, California
- Latitude/longitude—Lat. 41.21 N.; long. 121.63 W.
- Elevation—3,865 ft
- Soil parent material—Andesite and volcanic ash
- Species studied—Ponderosa pine
- Plot installation—1988
- Duration of data collection—1988-ongoing
- Measurement interval—2 years, changing to 5 years by age 10

Study design—
A completely randomized design with three replications was used. All measurement plots of 20 original trees are buffered with two rows of planted trees.

Measurements—

All trees within the plots were measured using diameter tapes (nearest 0.1 in) and height poles (nearest 0.1 ft). Stem deformities and evidence of insect and disease attack were also noted. Total height and height to live crown were measured on all trees, as well as crown diameter at the widest point (mean of two right-angle measurements).

Monumentation—

Treatment plot corners are numbered orange stakes, and measurement plot corners are white stakes. However, some of the stakes may be missing.

Whitmore Garden of Eden Plantation

History—

The area was site prepared in 1985 by tractor and brush rake from a manzanita brushfield that originated following a 1967 wildfire. Planting spots were surveyed by using transit and tape in early spring 1986 and bare root pine were planted shortly thereafter. Survival was essentially 100 percent. In March 1996, plots receiving the HI and HFI treatments were marked for thinning from below. Half the trees were thinned in March 1996, and two trees per plot (a smaller and a larger tree) were sampled for reconstructing stem and crown biomass. In 2006 soil cores were taken to a depth of 1 m for fine root analysis.

- Location—SE1/4 of sec. 18, T. 32 N., R.1 E., MDM on property managed by William Beaty and Associates, Redding, California
- Latitude/longitude—Lat. 40.62 N.; long. 121.90 W.
- Elevation—2,395 ft
- Soil parent material—Andesitic mudflow
- Species studied—Ponderosa pine
- Plot installation—1986
- Duration of data collection—1986-ongoing
- Measurement interval—2 years, changing to 5 years after age 10

Study design—

A completely randomized design with three replications was used. All measurement plots of 20 original trees are buffered with two rows of planted trees.

Measurements—

All trees within the plots were measured using diameter tapes (nearest 0.1 in) and height poles (nearest 0.1 ft). Stem deformities and evidence of insect and disease attack were also noted. Total height and height to live crown were measured on all trees, as well as crown diameter at the widest point (mean of two right-angle measurements). Forest floor samples and soil cores, to a 4-ft depth, were collected from C, F, H, and HF plots in 2005 for mass and chemical analyses. All vegetation was sampled in spring 2007 for complete analysis of above- and belowground biomass.

Monumentation—

Treatment plot corners are numbered orange stakes, and measurement plot corners are white stakes. However, some of the stakes may be missing.

IV. Long-Term Soil Productivity Studies

Long-Term Soil Productivity (LTSP) installations are part of the world's largest effort to understand how soil and site disturbances associated with tree harvest affect the capacity of the land to capture carbon and grow vegetation. The installations (12 in California, more than 100 in the United States and Canada) are providing soil-based indicators of sustainable site productivity (fig. 21). The treatments consist of two main factors: organic matter removal and soil compaction, and are designed to bracket the range of conditions likely to occur under such management practices as thinning for fuel reduction or wood production. Organic matter treatments consist of three treatment levels: stem removal (all slash retained), whole tree removal (forest floor retained), and complete removal (all vegetation and forest floor removed) (fig. 22). These organic matter treatments are crossed factorially with three levels of soil compaction: none, moderate, and severe (see fig. 23). The treatment plots are 1 ac each, usually nine plots per installation. All but one are on national forest lands, the exception being a research forest managed by the University of California. The California phase of LTSP began in 1991 and centers on mixed-conifer forests of the Sierra Nevada located on a broad range of soil types. All sites supported mature, mixed-conifer forests at the start of the study and all forests were sampled before treatment by felling trees for crown and stem biomass of the overstory, biomass of the understory, and mass of the forest floor to mineral soil, allowing the standing mass of organic matter to be estimated before treatments began. Soils also were sampled for a variety of physical and chemical properties. Plots (not necessarily contiguous) with similar degrees of variation in stand and soil

Long-Term Soil Productivity (LTSP) installations are part of the world's largest effort to understand how soil and site disturbances associated with tree harvest affect the capacity of the land to capture carbon and grow vegetation.

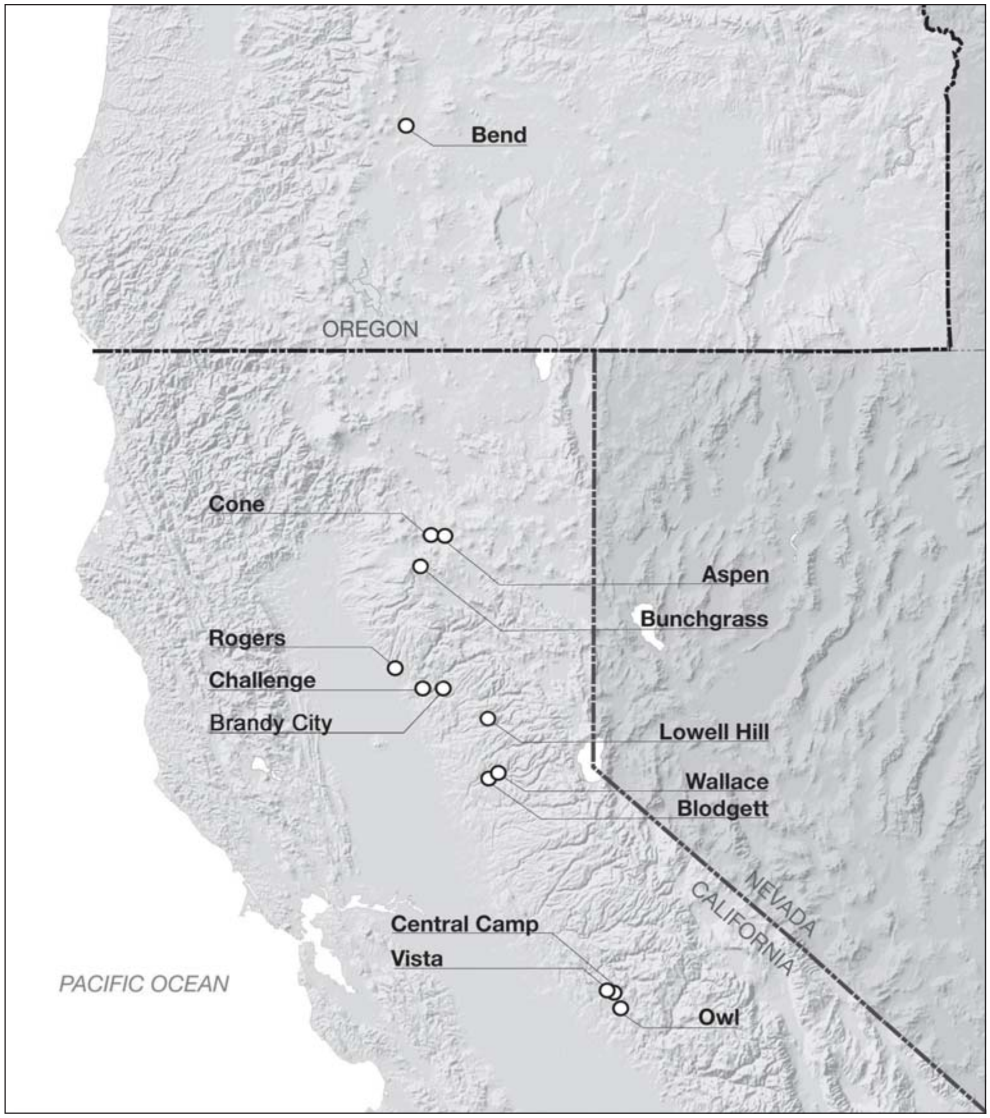


Figure 21—Long-Term Soil Productivity plots.

A

Bob Powers

B

Bob Powers

Figure 22—Challenge Long-Term Soil Productivity installation. Challenge is the oldest of the California installations. (A) Stem-only harvest in 1999 when the plantation was 2 years old. All logging slash is retained. (B) Complete organic matter removal in 1990. Mineral soil is exposed.

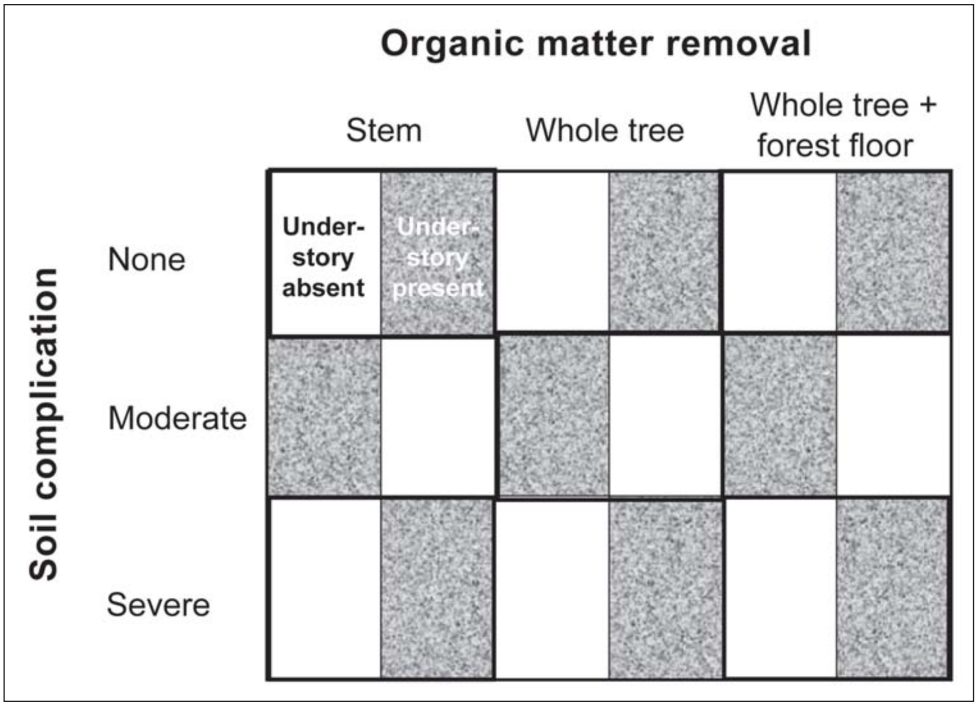


Figure 23—Generalized layout of nine 1-ac Long-Term Soil Productivity treatment plots (three levels of organic matter removal, three levels of soil compaction). Each plot is split, and understory vegetation is repeatedly controlled or not controlled.

conditions were clearcut (full suspension for noncompaction treatments) and the appropriate treatment plots compacted to specific soil bulk densities with mechanized vibrating rollers or stamping pads. All treatment plots are monumented at corners either with heavy wooden stakes or polyvinyl chloride (PVC) pipe over metal bars. Following LTSP treatment, plots were planted at an 8- by 8-ft spacing to a mixture of four conifer species, mimicking the species found in the overstory before harvest. Each 1-ac treatment plot is split into two halves, one with no control of understory revegetation, the other with understory eliminated by repeated chemical or mechanical treatment. Effects of disturbance treatments on productivity are measured by development of biomass production over time. In this way, the impacts of organic matter retention, soil compaction, and plant diversity on fundamental productivity can be measured and compared over time. Vegetation measurements are on a 5-year schedule for the first 15 years, and on a 10-year schedule thereafter. Typical measurements include tree diameter, height, crown dimensions, understory biomass, and soil bulk densities and chemical properties. The study is intended to continue for six decades. Unless otherwise noted, all installations are treated similarly.

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Aspen LTSP Installation

History—

The site is in the southern Cascade Mountains. The original forest was a 262-year-old, even-aged, mixed-conifer forest with a high proportion of ponderosa pine and white fir. Standing biomass was 171 Mg/ha (152,703 lb/ac).

- Location—NW1/4 sec. 21, T. 33 N., R. 8 E., MDM on land managed by the Lassen National Forest
- Latitude/longitude—Lat. 40.72 N.; long. 121.09 W.
- Elevation—5,870 ft
- Soil parent material—Andesite and volcanic ash
- Species studied—Ponderosa pine, sugar pine, white fir, Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco)

- Plot installation—1998
- Duration of data collection—1998-2007
- Measurement interval—5 years, changing to 10 years by age 15 on most installations

Study design—

Design follows the standard template shown in figure 23, although plots are not contiguous. Plot layout maps are available from the Pacific Southwest Research Station, Redding, California.

Monumentation—

All plots are 1 ac or 1/2 ac with large numbered posts at the plot corners. Measurement plots begin the third row of trees in from the treated edge.

Bend, Oregon, LTSP Affiliate Sites

History—

The Bend LTSP study (fig. 24) was identified as an affiliate site in the North American LTSP network based on its gradient of organic matter treatments. The purpose of the Bend study was to determine how combinations of thinning, prescribed fire, and nutrient additions affect ecosystem sustainability, productivity, and plant diversity in second-growth ponderosa pine forests. The scientific lead for the study was stationed at the Pacific Northwest Research Station's Bend Silviculture Laboratory, and was formally transferred to PSW, Redding, California, in 1996 following the closure of the Bend laboratory. The study is included in this publication because of its scientific value and because it is now overseen by PSW.

The pine forests in central Oregon burned frequently prior to the 20th century. Wildfires were predominantly low-severity ground fires, with less-frequent stand-replacement fires. The three study sites have been free of fire disturbance since clearcut harvesting in the 1920s and 1930s. Following railroad logging in the 1920s and 1930s, the forests were heavily stocked with naturally regenerated ponderosa pine. Precommercial thinning in the 1960s left 500 to 800 trees/hectare (202 to 324 trees/acre). By the mid-1980s, national forest concerns for potential catastrophic wildfire and insect mortality were acute, leading to accelerated treatment (thinning and burning) of the most actively-growing stands ("black bark" pine), and to the establishment of this large-scale study.

Figure 24—Bend, Oregon, Long-Term Soil Productivity plot (Unburned plot at East Fort Rock).

- Location—Swede Ridge (high-productivity site): Sec. 14, 19, 24, 25, and 30, T. 18 S., R.10, and 11 E. Sugar Cast (moderate-productivity site): sec. 10, 11, and 12, T. 20 S., R. 11 E. East Fort Rock (low-productivity site): sec. 4 and 5, T. 20 S., R. 13 E.
- Latitude/longitude—Swede Ridge (lat. 43.85; long. 121.35); Sugar Cast (lat. 43.84; long. 121.34); East Fort Rock (lat. 43.84; long. 121.32).
- Elevation—Swede Ridge: 4,990 ft; Sugar Cast: 4,590 ft; East Fort Rock: 5,100 ft
- Soil parent material—Windblown deposits of pumice and ash from the eruption of Mount Mazama. The soils are coarse textured (loamy sands) and relatively infertile
- Species studied—Ponderosa pine and associated understory vegetation
- Plot installation—1989
- Duration of data collection—1988-ongoing
- Measurement interval—5 years for tree growth, fuel loading, soil nutrients; 3 years for shrub cover and biomass; annually for herbaceous biomass.

Study design—

Study sites were selected along a west-to-east transect on the Deschutes National Forest to encompass the range of growing conditions for ponderosa pine (based on precipitation and site quality) on the pumice plateau in central Oregon. All trees within plots were measured prior to treatment for dbh and were cored for increment growth to (1) identify and, if necessary, eliminate nonrepresentative plots and (2) provide data for covariate analysis. Sixteen treatments were arranged in a 4 by 4 factorial design to compare combinations of thinning method, prescribed fire, and fertilization. Three additional treatments (pile and burn, pile and burn plus fertilize, and crush slash) were included to compare the long-term effects of slash treatment on soils and vegetation (see table 4).

Thinning was completed in 1989 by removing the smallest diameter trees plus those with visual signs of damage (forked tops, mechanical injury, insects, mistletoe). The prescription was selected by forest silviculturists to reduce stand basal areas from 25 to 32 m^2/ha (109.25 to 139.84 ft^2/ac) to 14 m^2/ha (61.18 ft^2/ac). Postthinning tree spacing was generally uniform at 6 by 6 m (19.68 by 19.68 ft). The objective of the thinning treatments (whole tree removal, bole-only removal, leave trees on sites) was to create a gradient of site organic matter, allowing for

Table 4—Treatment design of the Bend Long-Term Soil Productivity study

Treatment	Thinning method	Additional treatment
1	Whole-tree harvest	Fire
2	Whole-tree harvest	Fire + fertilize
3	Whole-tree harvest	Fertilize
4	Whole-tree harvest	None
5	Bole-only harvest	Fire
6	Bole-only harvest	Fire + fertilize
7	Bole-only harvest	Fertilize
8	Bole-only harvest	None
9	Thin, leave trees on site	Fire
10	Thin, leave trees on site	Fire + fertilize
11	Thin, leave trees on site	Fertilize
12	Thin, leave trees on site	None
13	No thin	Fire
14	No thin	Fire + fertilize
15	No thin	Fertilize
16	No thin	None
17	Bole-only harvest	Pile and burn
18	Bole-only harvest	Pile and burn + fertilize
19	Bole-only harvest	Crush slash

hypothesis testing that the retention of surface organics will lead to long-term changes in soil productivity.

Prescribed burning was conducted during late spring 1991, and repeated burns were conducted in spring 2002 to reduce the rapid buildup of woody shrubs. However, plots receiving fertilizer applications were not reburned in 2002 due to budget constraints (27 plots were burned in 1991; 12 plots were reburned in 2002). Pile burning was conducted in fall 1991.

Fertilizer (200 lb/ac nitrogen; 100 lb/ac phosphorus; 33 lb/ac sulfur) was applied in fall 1991 and 1996 based on soil nutrient limitations identified in earlier studies of ponderosa pine growth by Cochran (1978, 1979).

Each site contains a full replicate of 19 combinations of thinning, burning, and fertilizer treatments. The experimental design is a completely randomized block, with three replicate blocks (sites). Treatment plots are 0.92 ac and the interior measurement plots are 0.41 ac.

Measurements—

All trees within each plot were measured every 5 years using diameter tapes (nearest 0.1 in) and optical dendrometers (total height to nearest 0.1 ft). Tree damage, deformity, and evidence of insect and disease attack were noted. Shrub species, canopy cover, and biomass (using nondestructive site equations) were measured within three, 100-m (328-ft) belt transects per plot. Species richness and peak-season biomass of herbaceous plants were measured within 10 systematically located microplots per plot. Litter decay was measured in situ during a 3-year period (1992 to 1994) using fine-mesh litterbags. Wood decay was measured as the change in wood density of downed trees during periodic sampling between 1989 and 2007. Fuel loading and soil nutrients were measured every 5 years using conventional methods, and soil microbial community characteristics were measured periodically by substrate-induced respiration, phospholipid fatty acids, and carbon utilization patterns.

Monumentation—

Treatment plot corners and interior measurement plot corners (nondestructive sampling area) are monumented with T-fenceposts. Plot and treatment identification are scribed on 3-by 5-in metal tags attached to the corner T-fenceposts. All plot corners were global positioning system (GPS)-monumented, and their digitized locations are recorded and maintained by the Deschutes National Forest. All over-story trees were identified with numbered metal tags in 1989; understory trees are rare and have not been tagged.

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Blodgett LTSP Installation

History—

The site is on the western slope of the Sierra Nevada. The gentle relief led to railroad logging in the late 1800s, and most of the area had been logged by the 1930s. The forest existing at the time of this study was a 65-year-old, even-aged, mixed-conifer forest. Standing biomass was 352 Mg/ha (314,336 lb/ac).

- Location—SW1/4 sec. 16, T. 12 N., R. 12 E., MDM at Blodgett Research Forest managed by University of California
- Latitude/longitude—Lat. 38.89 N.; long. 120.64 W.
- Elevation—4,310 ft
- Soil parent material—Andesitic mudflow
- Species studied—Ponderosa pine**,** sugar pine, white fir, giant sequoia (*Sequoiadendron giganteum* (Lindl.) Buchholz)
- Plot installation—1994
- Duration of data collection—1994 to 2007
- Measurement interval—5 years, changing to 10 years by age 15 on most installations

Study design—

Design follows the standard template shown in figure 23, although plots are not contiguous. The Blodgett LTSP installation differs from the standard treatment format by the addition of mitigative treatments following severe disturbance. Two half-acre plots receiving complete surface organic removal and severe soil compaction were treated with a followup subsoiling treatment. Plot layout maps are available from the PSW Research Station in Redding, California.

Monumentation—

All plots are 1 or 1/2 ac with large numbered posts at the plot corners. Measurement plots begin the third row of trees in from the treated edge.

Brandy City LTSP Installation

History—

The site is on the western slope of the Sierra Nevada. The original forest was a 115-year-old, even-aged, mixed-conifer forest. Standing biomass was 357 Mg/ha (318,801 lb/ac).

- Location—E1/2 sec. 2, T. 19 N., R. 8 E., MDM on land managed by the Tahoe National Forest
- Latitude/longitude—Lat. 69.54 N.; long. 121.04 W.
- Elevation—3,725 ft
- Soil parent material—Andesitic mudflow
- Species studied—Ponderosa pine, sugar pine, white fir, giant sequoia
- Plot installation—1995
- Duration of data collection—1995 to 2007
- Measurement interval—5 years, changing to 10 years by age 15 on most installations

Study design—

Design follows the standard template shown in figure 23, although plots are not contiguous. Plot layout maps are available from the PSW Research Station in Redding, California.

Monumentation—

All plots are 1 or 1/2 ac with large numbered posts at the plot corners. Measurement plots begin the third row of trees in from the treated edge.

Bunchgrass LTSP Installation

History—

The site is in the southern Cascade Mountains. The original forest was a 242-year-old, even-aged, mixed-conifer forest with a high proportion of ponderosa pine and white fir. The stand probably originated following wildfire. Past entries primarily consisted of removals of beetle-killed trees until 1987 when there was some overstory removal in the vicinity of the LTSP study area, although the study site itself was not touched. Standing biomass averaged 207 Mg/ha (184,851 lb/ac) on the LTSP site.

- Location—Sec. 28, T. 32 N., R. 5 E., MDM on land managed by the Lassen National Forest

- Latitude/longitude—Lat. 40.61 N.; long. 121.43 W.
- Elevation—5,260 ft
- Soil parent material—Andesite and volcanic ash
- Species studied—Ponderosa pine, sugar pine, white fir, Douglas-fir
- Plot installation—1998
- Duration of data collection—1998 to 2007
- Measurement interval—5 years, changing to 10 years by age 15 on most installations

Study design—
Design follows the standard template shown in figure 23, although plots are not contiguous. Plot layout maps are available from the PSW Research Station in Redding, California.

Monumentation—
All plots are 1 or 1/2 ac with large numbered posts at the plot corners. Measurement plots begin the third row of trees in from the treated edge.

Central Camp LTSP Installation

History—
The site is on the western slope of the Sierra Nevada. The original forest was a 117-year-old, even-aged, mixed-conifer forest that regenerated naturally following railroad logging in the 1920s and 1930s. Standing biomass on the LTSP site averaged 422 Mg/ha (376,846 lb/ac).

- Location—S1/2 sec. 8, T. 7 S., R. 23 E., MDM on land managed by the Sierra National Forest
- Latitude/longitude—Lat. 37.33 N.; long. 119.48 W.
- Elevation—5,400 ft
- Soil parent material—Granodiorite
- Species studied—Ponderosa pine, sugar pine, white fir, giant sequoia
- Plot installation—1993
- Duration of data collection—1993 to 2007
- Measurement interval—5 years, changing to 10 years by age 15 on most installations

Study design—
Design follows the standard template shown in figure 23, although plots are not contiguous. Plot layout maps are available from the PSW Research Station in Redding, California.

Monumentation—
All plots are 1 or 1/2 ac with large numbered posts at the plot corners. Measurement plots begin the third row of trees in from the treated edge.

Challenge LTSP Installation

History—
The site is on the western slope of the northern Sierra Nevada. The original forest was a 108-year-old, even-aged, low-elevation, Sierra Nevada mixed-conifer forest with a high proportion of ponderosa pine. It originated following clearcutting and railroad logging and the slash fires that followed during the late 1800s. Standing biomass prior to LTSP treatment averaged 473 Mg/ha (422,389 lb/ac).

- Location—NW1/4 sec. 20, NE1/4 sec. 19, SE1/4 sec. 18, T. 19 N., R. 8 E., MDM on land managed by the PSW Research Station
- Latitude/longitude—Lat. 39.50 N.; long. 121.22 W.
- Elevation—2,765 ft
- Soil parent material—Metamorphosed basalt
- Species studied—Ponderosa pine, sugar pine, white fir, Douglas-fir
- Plot installation—1991
- Duration of data collection—1991 to 2007
- Measurement interval—5 years, changing to 10 years by age 15 on most installations

Study design—
Design follows the standard template shown in figure 23, although plots are not contiguous. Plot layout maps are available from the PSW Research Station in Redding, California. Following the initial treatments, herbicides were applied in June 1997, to the area bordering the plots, to reduce wildfire risk and improve access.

Monumentation—
All plots are 1 or 1/2 ac with large numbered posts at the plot corners. Measurement plots begin the third row of trees in from the treated edge.

Cone LTSP Installation

History—
The site is in the southern Cascade Mountains. The original forest was a 258-year-old, even-aged, mixed-conifer forest with a high proportion of ponderosa pine and white fir. Standing biomass was 213 Mg/ha (190,209 lb/ac).

- Location—SE1/4 sec. 7, T. 33 N., R. 8 E., MDM, at Blacks Mountain Experimental Forest managed by PSW Research Station
- Latitude/longitude—Lat. 40.73 N.; long. 121.12 W.
- Elevation—6,050 ft
- Soil parent material—Andesite and volcanic ash
- Species studied—Ponderosa pine, sugar pine, white fir, Douglas-fir
- Plot installation—1998
- Duration of data collection—1998 to 2007
- Measurement interval—5 years, changing to 10 years by age 15 on most installations

Study design—
Plot layout maps are available from the PSW Research Station in Redding, California.

Monumentation—
All plots are 1 or 1/2 ac with large numbered posts at the plot corners. Measurement plots begin the third row of trees in from the treated edge.

Lowell Hill LTSP Installation

History—
The site is on the western slope of the Sierra Nevada. The original forest was a 117-year-old, even-aged, mixed-conifer forest with a high proportion of ponderosa pine and sugar pine. Standing biomass was 438 Mg/ha (391,134 lb/ac).

- Location—S1/2 sec. 7, T. 16 N., R. 11 E., MDM on land managed by the Tahoe National Forest
- Latitude/longitude—Lat. 39.36 N.; long. 120.78 W.
- Elevation—4,160 ft
- Soil parent material—Basaltic mudflow
- Species studied—Ponderosa pine, sugar pine, white fir, giant sequoia
- Plot installation—1995
- Duration of data collection—1995 to 2007

- Measurement interval—5 years, changing to 10 years by age 15 on most installations

Study design—
Design follows the standard template shown in figure 23, although plots are not contiguous. The Lowell Hill LTSP installation differs from others in this series in the addition of mitigative treatments following severe disturbance. Three additional 1-ac units received complete organic matter removal and severe soil compaction. These also received full factorial followup combinations of subsoiling and nitrogen and phosphorus fertilization. Plot layout maps are available from the PSW Research Station in Redding, California.

Monumentation—
All plots are 1 or 1/2 ac with large numbered posts at the plot corners. Measurement plots begin the third row of trees in from the treated edge.

Owl LTSP Installation

History—
The site is on the western slope of the Sierra Nevada. The original forest was a 115-year-old, even-aged, mixed-conifer forest that regenerated naturally following railroad logging in the 1920s and 1930s. Standing biomass averaged 576 Mg/ha (514,368 lb/ac) on the LTSP site.

- Location—S1/2 sec. 12, N. 1/2 sec. 13, T. 8 S., R. 23 E., MDM on land managed by the Sierra National Forest
- Latitude/longitude—Lat. 37.24 N.; long. 119.41 W.
- Elevation—6,060 ft
- Soil parent material—Granodiorite
- Species studied—Ponderosa pine, sugar pine, white fir, giant sequoia
- Plot installation—1993
- Duration of data collection—1993 to 2007
- Measurement interval—5 years, changing to 10 years by age 15 on most installations

Study design—
Design follows the standard template shown in figure 23, although plots are not contiguous. Plot layout maps are available from PSW Research Station in Redding, California.

Monumentation—

All plots are 1 or 1/2 ac with large numbered posts at the plot corners. Measurement plots begin the third row of trees in from the treated edge.

Rogers LTSP Installation

History—

The site is on the western slope of the Sierra Nevada. The original forest was a 112-year-old, even-aged, mixed-conifer forest with a high proportion of ponderosa pine and sugar pine. Standing biomass was 494 Mg/ha (441,142 lb/ac). The original forest was logged by the Swain Lumber Company in the early 1900s, and some of the area burned after the logging.

- Location—SE1/4 sec. 8, SW1/4 sec. 9, T. 22 N., R. 6 E., MDM on land managed by the Plumas National Forest
- Latitude/longitude—Lat. 39.77 N.; long. 121.32 W.
- Elevation—4,100 ft
- Soil parent material—Granodiorite
- Species studied—Ponderosa pine, sugar pine, white fir, Douglas-fir
- Plot installation—1996
- Duration of data collection—1996 to 2007
- Measurement interval—5 years, changing to 10 years by age 15 on most installations

Study design—

Design follows the standard template shown in figure 23, although plots are not contiguous. Plot layout maps are available from PSW Research Station in Redding, California.

Monumentation—

All plots are 1 or 1/2 ac with large numbered posts at the plot corners. Measurement plots begin the third row of trees in from the treated edge.

Vista LTSP Installation

History—

The site is on the western slope of the Sierra Nevada. The original forest was a 132-year-old, even-aged, mixed-conifer forest that regenerated naturally following railroad logging in the 1920s and 1930s. Standing biomass on the LTSP site averaged 374 Mg/ha (333,982 lb/ac).

- Location—E1/2 sec. 28, T. 6 S., R. 22 E., MDM on land managed by the Sierra National Forest
- Latitude/longitude—Lat. 37.38 N.; long. 119.56 W.
- Elevation—5,220 ft
- Soil parent material—Granodiorite
- Species studied—Ponderosa pine, sugar pine, white fir, giant sequoia
- Plot installation—1993
- Duration of data collection—1993 to 2007
- Measurement interval—5 years, changing to 10 years by age 15 on most installations

Study design—
Plot layout maps are available from PSW Station in Redding, California.

Monumentation—
All plots are 1 or 1/2 ac with large numbered posts at the plot corners. Measurement plots begin the third row of trees in from the treated edge.

Wallace LTSP Installation

History—
The site is on the western slope of the Sierra Nevada. The original forest was a 230-year-old, even-aged, mixed-conifer forest. Standing biomass was 230 Mg/ha (205,390 lb/ac).

- Location—SW1/4 sec. 15, T. 13 N., R. 13 E., MDM on land managed by the Eldorado National Forest
- Latitude/longitude—Lat. 38.97 N.; long. 120.52 W.
- Elevation—5,150 ft
- Soil parent material—Volcanic ash
- Species studied—Ponderosa pine, sugar pine, white fir, giant sequoia
- Plot installation—1993
- Duration of data collection—1993 to 2007
- Measurement interval—5 years, changing to 10 years by age 15 on most installations

Study design—
Plot layout maps are available from PSW Research Station in Redding, California.

Monumentation—
All plots are 1 or 1/2 ac with large numbered posts at the plot corners. Measurement plots begin the third row of trees in from the treated edge.

V. Continuous Forest Inventory Plots

Below is a supplemental list of growth plots that have been managed and maintained by The California Department of Forestry and Fire Protection (CDF). The CDF is currently digitizing publications from the past 50 years that were produced from research undertaken at Demonstration State Forests. These digitized publications are now available online at http://www.demoforests.net/. A brief description of Demonstration State Forests can be found at http://www.fire.ca.gov/rsrc-mgt_sf.php. For more information regarding these plots, their relevant publications, and Demonstration State Forests, contact the California State Forests Program, California Department of Forestry and Fire Protection, 916-653-7209.

Boggs Mountain Demonstration State Forest

History—
Boggs Mountain Demonstration State Forest was established in 1949 for the purpose of studying and demonstrating forest management practices in second-growth coast range mixed-conifer forest.

- Location—Lake County
- Latitude/longitude—Lat. 38.83 N.; long. 122.70 W.
- Species studied—Ponderosa pine and Douglas-fir

Monitoring plots—
These are ten 2.5-ac plots that have been measured 10 times since 1952. Trees over 11 in dbh are stem mapped. There is a subsample of tree heights. All data resides in an Access database. The latest measurement took place in 2005.

Continuous Forest Inventory (CFI)—
There are four measurements (5-year intervals) of these permanent plots (first in 1991). The last measurement took place in 2006.

Jackson Demonstration State Forest

History—

The Jackson Demonstration State Forest was established in 1947 for the purpose of studying and demonstrating economical forest management practices for young-growth coast redwood forest.

- Location—Mendocino County
- Latitude/longitude—Lat. 39.35 N.; long. 123.63 W.
- Species studied—Coast redwood

Railroad Gulch—

These permanent plots were established in 1982 and measured three times. Growth is monitored for redwood and Douglas-fir in individual-tree and group-selection cutting treatments. Uncut controls are also included. The last inventory in 2002 included a botanical survey.

Continuous Forest Inventory—

These plots were installed in 1958 through 1959 on a systematic grid (142 plots). They have been remeasured every 5 years with the last measurement occurring in 2005. These plots were a major source of growth information for CRYPTOS, the primary redwood region tree growth simulator. These data are in an Access database.

LaTour Demonstration State Forest

History—

LaTour Demonstration State Forest was established in 1949 for the purpose of studying and demonstrating forest management practices in second-growth Sierra Nevada mixed-conifer forest, as well as in true fir stands.

- Location—Shasta County
- Latitude/longitude—Lat. 40.63 N.; long. 121.70 W.
- Species studied—Mixed conifer and true fir

Continuous Forest Inventory—

These 221 permanent plots were installed in 1964 through 1965 and have been remeasured every 5 years. The latest measurement was in 2005. These data reside in an Access database.

Mountain Home Demonstration State Forest

History—

Mountain Home Demonstration State Forest was established in 1946 both for the purpose of demonstrating forest management practices in second-growth forests and to provide recreational opportunities to the public. This dual purpose stems from California's desire to preserve old-growth sequoias in the forest and provide the public with opportunities to visit those sequoias.

- Location—Tulare County
- Latitude/longitude—Lat. 36.23 N.; long. 118.66 W.
- Species studied—Mixed conifer and giant sequoia

Continuous Forest Inventory—

Plots were installed in 1970 and are remeasured every 5 years. The data reside in an Access database.

Giant Sequoia Old-Growth Inventory—

Approximately three-quarters of the 6,000+ old-growth giant sequoia trees on the forest have been located using GPS and measured.

Soquel Demonstration State Forest

History—

Established in 1988 on land that was originally part of a Mexican land grant, the Soquel Demonstration State Forest provides public access to coast redwoods and opportunities for forestry education and outdoor recreation. It is close to both the San Francisco and Monterey Bay regions, making it accessible to urban communities.

- Location—Santa Cruz County
- Latitude/longitude—Lat. 37.08 N.; long. 121.90 W.
- Species studied—Redwood; close to urban center

Sudden oak death plots and transects—

These permanent plots were installed in 2001 and have been measured three times to determine the severity of infection and ecological response.

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Metric Equivalents

When you know:	Multiply by:	To find:
Inches (in)	2.54	Centimeters (cm)
Feet (ft)	.3048	Meters (m)
Acres (ac)	.405	Hectares (ha)
Milacres	.000405	Hectares (ha)
Square feet (ft^2)	.0929	Square meters (m^2)
Square feet per acre (ft^2/ac)	.229	Square meters per hectare (m^2/ha)
Pounds per acre (lb/ac)	1.12	Kilograms per hectare (kg/ha)
Pounds per acre (lb/ac)	.00112	Metric tons per hectare (Mg/ha)
Trees per acre	2.471	Trees per hectare

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