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# True Fir-Hemlock Spacing Trials: Design and First Results

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## Abstract

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A series of 18 precommercial thinning trials was established in true fir-hemlock stands in the Olympic Mountains and along the west side of the Cascade Range in Washington and Oregon from 1987 through 1994. This paper documents establishment of these installations and presents some preliminary observations and results. Substantial differences in growth rates in height and diameter were observed among Pacific silver fir, western hemlock, and noble fir. Diameter growth of all species increased as spacing increased, but height growth of silver fir and noble fir decreased at wider spacings in some areas. These installations will provide a unique source of information on early development of managed stands of these species, for which little information now is available.

Keywords: *Abies*, spacing, precommercial thinning, true firs.

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## Introduction

Little is known about the effects of early spacing control on subsequent development of high-elevation true fir-hemlock stands in the Cascade Range and Olympic Mountains of western Oregon and Washington, beyond analogy with other species. In the period 1987-94, 18 precommercial thinning trials were established in true fir-hemlock stands in the Olympic Mountains and along the west side of the Cascade Range in Washington and Oregon. This report documents establishment of these trials and presents some initial results.

The stands studied are within the Coastal True Fir-Hemlock Type (Society of American Foresters type 226; Eyre 1980), primarily within the *Abies amabilis* zone (Franklin and Dryness 1973) but also with a few in the *Tsuga mertensiana* zone. The primary tree species are Pacific silver fir (*Abies amabilis* Dougl. ex Forbes), noble fir (*A. procera* Rehd.), and western hemlock (*Tsuga heterophylla* (Raf.) Sarg.). Other minor associated species include western redcedar (*Thuja plicata* Donn ex D. Don), Alaska-cedar (*Chamaecyparis nootkatensis* (D. Don) Spach), mountain hemlock (*Tsuga mertensiana* (Bong.) Carr.), subalpine fir (*A. lasiocarpa* (Hook.) Nutt.), Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), and western white pine (*Pinus monticola* Dougl. ex D. Don).

True fir-hemlock forests at higher elevations in the Cascade Range and Olympic Mountains play major roles as protective cover for watersheds and snowpacks, as viewscapes in recreational landscapes, and as timber-producing forests. True firs are often the most important tree species found at upper elevations in headwater areas of major river systems. Major acreages of true fir-hemlock exist in the Mount Baker-Snoqualmie (MBS), Gifford Pinchot (GP), Olympic (OLY), Mount Hood (MH), and Willamette (WIL) National Forests as well as on Washington Department of Natural Resources (WDNR) lands.

### Previous Research

Only very limited information is available on potential yields and stand development patterns of true fir-hemlock stands grown under any form of management. There is a considerable body of information on stand development, yields, and site evaluation for low-elevation western hemlock (Barnes 1962; Bonnor and others 1995; Hann and others 1997; Meyer 1937; Wiley 1978a, 1978b; Wiley and Chambers 1981); however, few or no data used in these works were from the high-elevation true fir-hemlock type, and the results are not directly applicable.

Height growth and site index estimates, based on stem analysis of trees from unmanaged old-growth stands, were developed by Herman and others (1978) for noble fir and by Hoyer and Herman (1989) for Pacific silver fir. These height growth and site index curves, developed from stem analyses of very old trees, are only doubtfully applicable to young stands because of differences in stand establishment, early competition, climatic changes, and possible biases associated with changes in tree position over time.

Murray and others (1991) found that early height growth of young Pacific silver fir and noble fir established in clearcuts appeared to be considerably more rapid than predicted by the existing site curves. Harrington and Murray (1982) compared height-growth patterns in young Pacific silver fir, noble fir, and Douglas-fir. They point out that true firs characteristically have a period of slow juvenile growth, an extended period of almost linear rapid growth, and a final phase of appreciable growth extending to very advanced ages. Consequently, true firs often appear at an initial disadvantage in comparison with associated species but later may equal or surpass the associated species because of their long period of rapid and uniform height growth.

The proceedings of a true fir symposium (Oliver and Kenady 1982) provide a summary of existing information as of 1982.

## Past Management

Extensive harvesting in the true fir-hemlock type began in the early 1950s. Early operations commonly followed practices that had been generally successful in lower elevation Douglas-fir: namely, clearcut, burn, and plant—often with Douglas-fir. A high proportion of these early plantations failed, partially or wholly, and regeneration to true fir-hemlock took place by natural seeding over an extended number of years. The resulting stands often were patchy and contained considerable variability in tree sizes and ages. Over subsequent years, better species selection coupled with improved nursery, site preparation, and planting practices greatly improved survival and produced many successful plantations. Favored species for planting have been noble fir or noble and silver fir mixtures, with other species such as Engelmann spruce (*Picea engelmannii* Parry ex Engelm.) or western white pine used on some frost-prone sites. Reduced use of fire in recent decades has favored survival of natural advance regeneration of Pacific silver fir and western hemlock. As a result, numerous young true fir-hemlock stands now exist at higher elevations along the west side of the Cascade Range and in the Olympic Mountains.

Considerable operational precommercial thinning has been done, with specifications derived from recommendations for low-elevation Douglas-fir (e.g., Reukema 1975), modified more or less arbitrarily to allow for the narrower crowns of true firs and the expectation that later commercial thinning might not be feasible or even desirable. Doubts about commercial thinning arose from the facts that many stands are on steep terrain and that these thin-barked species are highly susceptible to rot arising from logging injuries.

A common practice in the late 1970s and early 1980s was to thin at an early age to 350 to 400 stems per acre (Boecksteigel 1982, Deer 1982, Husted and Korelus 1982, Pojar 1982). More recently, the trend has been to reduce the number of leave trees to as few as 200 stems per acre, with the expectation that no further stand entry would be needed until final harvest. This situation raised several concerns about the effects of number of residual trees and average tree size at which precommercial thinning (PCT) is done:

1. Tree size at harvest
2. Volume production
3. Establishment and development of tree regeneration and ground vegetation following PCT
4. Changes in biodiversity and stand structure
5. Losses from snow breakage and sun scald
6. Possible development of excessively large branches and knots.

## The Study

In 1987 the MBS National Forest asked the Pacific Northwest Research Station (PNW) for assistance in designing and establishing an administrative study to investigate the effects of early spacing control in young stands of Pacific silver fir and hemlock. Concurrently, the Washington, DC, office of the USDA Forest Service solicited proposals related to growth and yield needs of the National Forests. A PNW proposal was funded and provided starting money for this study. Work in later years was partially supported by the Pacific Northwest Region of the USDA Forest Service.

### Objectives

Study objectives were (1) to determine the quantitative responses of Pacific silver fir, noble fir, and western hemlock to a range of precommercial thinning stocking levels; and (2) to obtain long-term growth data applicable to young managed stands, as a basis for estimates of development patterns and potential yields.

Quantitative responses to precommercial thinning levels include:

1. Effect of residual number of trees on—
   a. size of trees produced
   b. volume yield
   c. understory and ground vegetation establishment and development
   d. branch size and other tree characteristics

2. Effect of stand development stage at which PCT is done on—
   a. subsequent development of leave trees
   b. establishment and development of ingrowth trees
   3. losses from snow breakage and sun scald

Spacing trials were established in stands considered ready for PCT under then-current operational practices. The effect of tree size at time of PCT on response was not directly addressed, although there was some range in stage of stand development at time of PCT. These trials ultimately should provide:

1. A factual basis for choosing the optimum number of leave trees to meet management objectives.
2. Information on development of precommercially thinned stands needed for reliable estimates of productivity of young true fir-hemlock stands.
3. Data useful, in combination with data from managed stand inventories, for construction of stand simulators and yield projection systems for young-growth managed stands.

### Study Area

The study area consists of the true fir-hemlock type as it occurs on the MBS, OLY, GP, MH, and WIL National Forests. Emphasis is on stands located within the Pacific silver fir zone; however, several trials reach into the lower portion of the mountain hemlock zone.

In 1987, a 12-plot spacing trial was established in a Pacific silver fir stand in the Mount Baker Ranger District as a joint effort between PNW and the MBS National Forest. In 1988, three additional six-plot trials were established in the MBS National Forest, followed by three more in 1989. From 1990 to 1994, additional spacing trials were established in other forests to total 18 trials established over 8 years: one in the OLY; five in the GP, including two additional 12-plot trials; four in the MH; and one in the WIL (fig. 1).

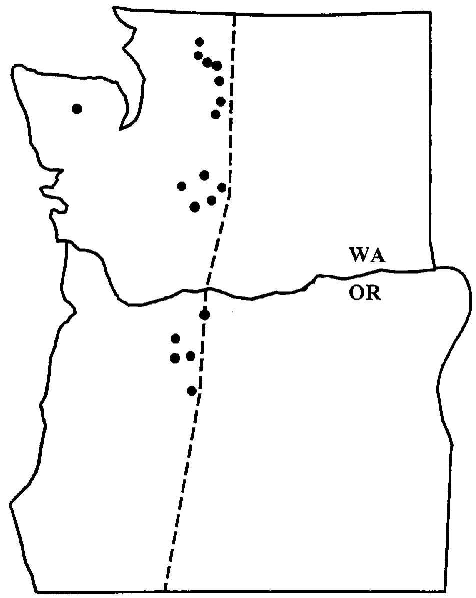


Figure 1–Locations of study sites in western Washington and Oregon.

For some years prior to the study, the National Forests had been conducting an extensive PCT program in young true fir-hemlock. Consequently, choice of locations was constrained by the fact that most stands otherwise suitable for the study already had been operationally thinned.

## Study Design

The original basic design consisted of six treatments, with five plots at various spacings and one untreated plot. Where feasible, two plots of each treatment were established at a location for a total of 12 plots per installation. Few relatively homogeneous areas large enough to accommodate 12-plot installations were found, however. Of the 18 installations established, 3 have 12 plots and 15 have 6 plots.

**Treatments—**The treatments consist of five spacings, plus no treatment (NT). The untreated plot(s) will be useful for demonstration purposes and in analytical comparisons. The spacings and corresponding per unit area values are as follows:

| Spacing | Trees per acre | Area per tree |
|---|---|---|
| *Feet* | *Number* | *Square feet* |
| 7.9 | 700 | 62.2 |
| 10.1 | 430 | 101.2 |
| 12.8 | 265 | 164.6 |
| 16.4 | 163 | 267.7 |
| 20.9 | 100 | 435.5 |

Seven hundred and one hundred trees per acre were chosen as the limits of the range considered, and intermediate values were calculated by using a constant percentage of increase in area per tree. Treatments were randomly allocated to plots within an installation.

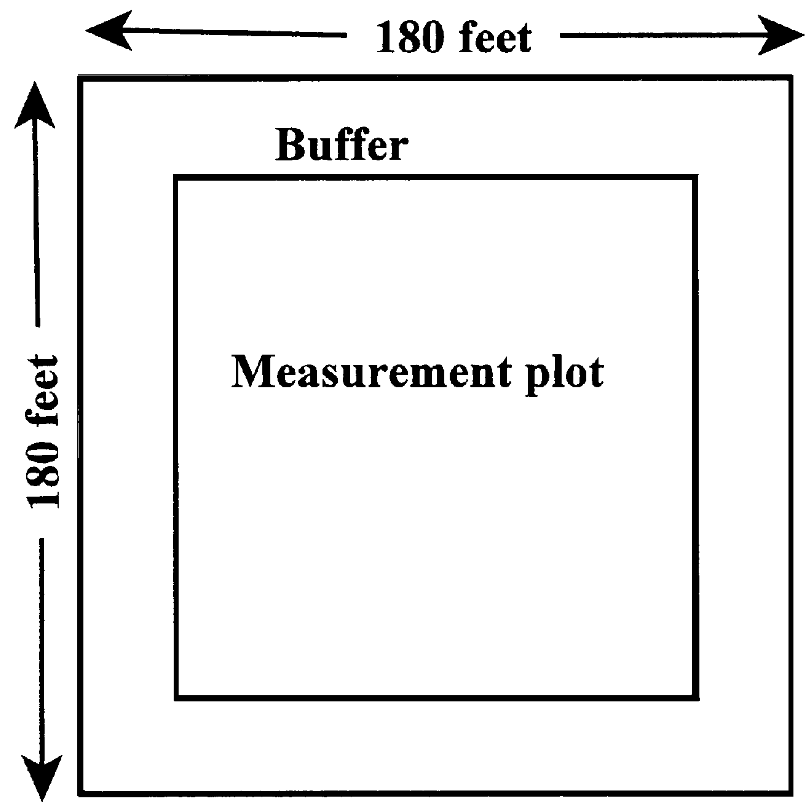


Figure 2–Basic plot design.

Plots were subdivided with string at intervals equal to the desired spacing, and leave trees were selected as the best stem within each grid cell. Because some cells within the grid lacked suitable leave trees, the specified numbers of leave trees per acre were not met exactly in all cases. To the extent possible, an effort was made to adjust all treated plots within an installation to nearly comparable species composition.

**Plot design—**Excessively large plots are expensive and rapidly use up available area. Excessively small plots pose difficulties in analysis, particularly in somewhat patchy stands and at older ages. The plot sizes selected were thought to be sufficient to (1) give reasonably smooth diameter distributions, (2) give values reasonably stable in the presence of minor mortality, and (3) allow continuation of the plot to advanced ages, with or without one superimposed later thinning.

We used square measurement plots within a larger treatment plot (fig. 2), of the dimensions given in table 1. In most installations, treatment plots are 180 by 180 feet. Two of the earlier installations have treatment plots 200 by 200 feet, and owing to space limitations, several installations have treatment plots 160 by 160 feet.

Measurement plot size is about 0.25 acre, with a slightly smaller plot (0.20 acre) for the unthinned control and slightly larger plot areas for the two widest spacings so that a reasonable number of leave trees would be included. To facilitate control of leave-tree

Table 1—Standard dimensions of plots used in the true fir-hemlock spacing trials

| Treatment plot | | | | Measurement plot | | Buffer width |
|---|---|---|---|---|---|---|
| N/acre[a] | Spacing | Area | Side | Area | Side | |
| | *Feet* | *Acres* | *Feet* | *Acres* | - - - - *Feet* - - - - | |
| No treatment | -- | 0.7438 | 180 | 0.200 | 93.3 | 43.4 |
| 700 | 7.9 | .7438 | 180 | .242 | 102.7 | 38.6 |
| 430 | 10.1 | .7438 | 180 | .234 | 101.0 | 39.5 |
| 265 | 12.8 | .7438 | 180 | .241 | 102.4 | 38.8 |
| 163 | 16.4 | .7438 | 180 | .302 | 114.8 | 32.6 |
| 100 | 20.9 | .7438 | 180 | .361 | 125.4 | 27.3 |

[a] Expected number assuming no empty cells.

marking, the sides of the measurement plot were made multiples of the desired spacing, thus allowing subdivision of the plot into strips of width corresponding to the desired spacing.

## Plot Establishment and Measurement Procedures

**Plot layout—**True fir-hemlock stands are characteristically patchy and some variation is unavoidable, but plot locations were selected to be as nearly comparable in site conditions and initial stand conditions as feasible. Plots were either contiguous or quite close to each other. Obvious site changes and root rot pockets were excluded. Plots were positioned to minimize the number of empty cells at an 8- by 8-foot spacing. Treatments were assigned randomly after the treatment plots were marked on the ground but before the measurement plots were established.

After initial plot location and treatment assignment, the corners of treatment plots and interior measurement plots were established with staff compass and tape. All distances were measured horizontally. Measurement plot boundary closure was within 2 feet.

**Initial tree measurements and marking—**All trees 0.6 inch in diameter at breast height (d.b.h.) and larger were tallied by species and 1-inch d.b.h. classes at all measurement plots to be thinned. These stem tallies were used to calculate trees per acre by plot, d.b.h. class, and species for all trees and for the largest 100 trees per acre.

Leave trees were selected to be vigorous and as uniformly spaced as feasible; these were usually the most “suitable” trees near nominal grid points as determined by measurement along the previously established strips (see “Treatments,” above). Vigor was given precedence over strict adherence to spacing or species criteria. The occasional exceptionally large tree was excluded to make leave tree diameter distributions and average diameters more comparable.

Dead limbs were removed up to head height on leave trees to facilitate tagging and d.b.h. measurements. A few live limbs were removed (with hand saws to avoid bole damage) as needed to provide access to the d.b.h. measuring point.

**Leave tree measurements—**Trees were measured after the growing season. Diameters at breast height were measured to the nearest 0.1 inch (by diameter tape) on all leave trees on thinned plots and all trees 0.6 inch and larger d.b.h. on unthinned plots. Heights and heights to live crown were measured to the nearest 0.1 foot (with height poles). Hemlock heights were measured to the visually estimated position of the leader tip were it fully extended vertically. Heights were measured on all leave trees at the two widest spacings, on the first two out of every three trees at the 12.8- by 12.8-foot spacing, and on every other tree (half of the trees) at the two closest spacings.

In unthinned plots, heights and heights to live crown were measured for at least 40 trees, more in mixed-species stands. Sample trees were selected in approximate proportion to species composition, but included at least 12 trees for each major species. Trees selected were distributed across the entire plot and across the full range of d.b.h. classes present, with about two-thirds of selected trees above the average diameter and one-third below for each species.

**Stand age estimates—**Ring counts were made at breast height (b.h.) and stump height on a sample of trees cut in thinning, but trees showing a suppressed core were omitted. There was considerable variation, because of differences in species growth rates and because natural regeneration often occurred over several years. Regressions of ring count on d.b.h. were fit to all sample tree data from an individual installation. These equations then were used to estimate the average number of rings at breast and stump heights corresponding to the mean diameter of leave trees on all treated plots at an installation. “Total age” was taken as the estimated number of rings at stump + 3 (table 2) and checked against date of planting in cases of known planting date and good survival. Seedlings established as advance regeneration (principally Pacific silver fir) may have widely differing numbers of years in a suppressed condition that are not included in the above age estimates.

**Description of ground vegetation—**All installations were classified by dominant plant association (tables 2 and 3), in most cases by the area ecologist for the given National Forest.

Highly detailed descriptions were made for those installations located in the MBS and OLY National Forests. The procedure used is described below:

Vegetation present on each measurement plot was described by procedures and codes similar to those in Henderson and others (1989, 1992). Boundaries were the same as for the plot used for the tree measurements. All vascular plants present were identified and recorded by species and percentage of cover by using standard codes. An attempt also was made to identify and record all mosses, lichens, and liverworts present. Percentage of cover was recorded for ground vegetation (shrubs and herbs), and abundance class was recorded for epiphytes. Tree seedlings and saplings were

**Table 2—Basic descriptive information for the true fir-hemlock spacing study installations**

| Installation | NF[a] | Plots | Plots established | Stand origin[b] | Age at b.h. | Age at stump | Total age | Measurements, 1998 | Elev. | Dominant plant association[c] |
|---|---|---|---|---|---|---|---|---|---|---|
| | | *No.* | *Year* | | - - - - - | *Years* | - - - - - | *No.* | *Feet* | |
| Alpine #4 | MH | 6 | 1990 | M | 11 | 16 | 19 | 2 | 4500 | TSME/VAME/CLUN |
| Bonidu | OLY | 6 | 1990 | N | 16 | 21 | 24 | 2 | 3000 | ABAM/VAAL/CLUN |
| Cabin #2 | GP | 6 | 1994 | P | 7 | 11 | 14 | 1 | 3800 | ABAM/BENE |
| Cat Creek | GP | 6 | 1990 | N | 13 | 20 | 23 | 2 | 4300 | ABAM/RHAL |
| Crevice Creek | MBS | 6 | 1988 | M | 22 | 26 | 29 | 3 | 3000 | ABAM/VAAL/CLUN |
| Cumberland | MBS | 6 | 1988 | N | 12 | 17 | 20 | 3 | 3200 | ABAM/VAAL/CLUN |
| Dog Creek | MH | 6 | 1991 | P | 13 | 17 | 20 | 2 | 3600 | ABAM/RHMA/XETE |
| Evans Creek | MBS | 6 | 1989 | N | 32 | 38 | 41 | 2 | 3700 | ABAM/VAAL/CLUN |
| Haller Pass | MBS | 5 | 1989 | P | 24 | 29 | 32 | 2 | 4200 | ABAM/VAME |
| Iron Mountain | MBS | 12 | 1987 | N | 19 | 25 | 28 | 3 | 3500 | ABAM/VAAL/CLUN |
| Job #2 | GP | 6 | 1992 | P | 8 | 14 | 17 | 2 | 3700 | ABAM/ACTR/CLUN |
| Marys Creek | WIL | 6 | 1994 | P | 8 | 12 | 15 | 1 | 4000 | ABAM/RHMA/BENE |
| Memaloose | MH | 6 | 1992 | P | 13 | 21 | 24 | 2 | 4000 | ABAM/RHMA/XETE |
| North Mountain #2 | MH | 6 | 1993 | M | 12 | 17 | 20 | 2 | 3200 | ABAM/VAAL/COCA |
| Pointer #3 | GP | 12 | 1991 | P | 10 | 14 | 17 | 2 | 4100 | TSME/VAME/XETE |
| Rattrap Pass | MBS | 6 | 1988 | M | 14 | 20 | 23 | 3 | 3200 | ABAM/VAAL/CLUN |
| Tonga Ridge | MBS | 6 | 1989 | M | 20 | 26 | 29 | 2 | 3800 | ABAM/VAAL/CLUN |
| Twin #1 | GP | 12 | 1994 | P | 10 | 15 | 18 | 1 | 3800 | ABAM/VAME/CLUN |

[a] National Forests (NF) as follows: GP=Gifford Pinchot, MH=Mount Hood, MBS=Mount Baker-Snoqualmie, OLY=Olympic, WIL=Willamette.
[b] P = planted, N = natural, M = mixed planted and natural.
[c] Plant associations are given in table 3.

**Table 3—Species and plant associations, true fir-hemlock spacing trials**

| Species | | |
|---|---|---|
| Common name | Botanical name | Acronym |
| Pacific silver fir | *Abies amabilis* | ABAM |
| Noble fir | *Abies procera* | ABPR |
| Douglas-fir | *Pseudotsuga menziesii* | PSME |
| Western hemlock | *Tsuga heterophylla* | TSHE |
| Mountain hemlock | *Tsuga mertensiana* | TSME |
| Alaska huckleberry | *Vaccinium alaskaense* | VAAL |
| Big huckleberry | *Vaccinium membranaceum* | VAME |
| Cascades azalea | *Rhododendron albiflorum* | RHAL |
| Rhododendron | *Rhododendron macrophyllum* | RHMA |
| Dwarf Oregon grape | *Berberis nervosa* | BENE |
| Vanilla leaf | *Achlys triphylla* | ACTR |
| Queen's cup beadlilly | *Clintonia uniflora* | CLUN |
| Bunchberry dogwood | *Cornus canadensis* | COCA |
| Beargrass | *Xerophyllum tenax* | XETE |

| Plant associations | |
|---|---|
| Pacific silver fir/Alaska huckleberry/queenscup beadlilly | ABAM/VAAL/CLUN |
| Pacific silver fir/big huckleberry | ABAM/VAME |
| Pacific silver fir/big huckleberry/queenscup beadlilly | ABAM/VAME/CLUN |
| Pacific silver fir/Cascade azalea | ABAM/RHAL |
| Pacific silver fir/rhododendron/queenscup beadlilly | ABAM/RHMA/XETE |
| Pacific silver fir/vanillaleaf/queenscup beadlilly | ABAM/ACTR/CLUN |
| Pacific silver fir/Alaska huckleberry/bunchberry | ABAM/VAAL/COCA |
| Pacific silver fir/rhododendron/dwarf Oregon grape | ABAM/RHMA/BENE |
| Pacific silver fir/dwarf Oregon grape | ABAM/BENE |
| Mountain hemlock/big huckleberry/queenscup beadlilly | TSME/VAME/CLUN |

Sources: Brockway and others 1983; Henderson and others 1989, 1992; Logan and others 1987.

**Table 4—Pretreatment descriptive statistics for the true fir-hemlock spacing study installations, trees 0.6 inch d.b.h or greater, all species combined**

| Installation name | Trees/acre | Basal area | QMD[a] | D40[b] | H40[c] |
|---|---|---|---|---|---|
| | *No.* | *$Ft^2$/acre* | - - - - - *Inches* | - - - - - | *Feet* |
| Alpine #4 | 1337 | 39.4 | 2.32 | 4.82 | 19.8 |
| Bonidu | 2343 | 100.0 | 2.80 | 6.96 | 34.6 |
| Cabin #2 | 796 | 21.9 | 2.25 | 3.88 | 17.7 |
| Cat Creek | 1995 | 30.0 | 1.66 | 3.99 | 21.2 |
| Crevice Creek | 2390 | 183.5 | 3.75 | 10.16 | 44.8 |
| Cumberland | 2716 | 65.0 | 2.09 | 5.05 | 24.1 |
| Dog Creek | 1849 | 44.2 | 2.09 | 4.88 | 24.1 |
| Evans Creek | 2675 | 181.4 | 3.53 | 10.00 | 53.0 |
| Haller Pass | 742 | 143.6 | 5.96 | 9.36 | 47.7 |
| Iron Mountain | 1453 | 47.8 | 2.46 | 5.56 | 27.6 |
| Job #2 | 783 | 26.4 | 2.49 | 4.18 | 20.7 |
| Marys Creek | 1134 | 23.4 | 1.95 | 3.96 | 19.9 |
| Memaloose | 1721 | 49.0 | 2.29 | 5.47 | 23.5 |
| North Mountain #2 | 976 | 39.3 | 2.72 | 5.84 | 25.5 |
| Pointer #3 | 543 | 14.3 | 2.20 | 4.92 | 22.0 |
| Rattrap Pass | 1256 | 72.2 | 3.25 | 6.98 | 32.3 |
| Tonga Ridge | 1465 | 137.6 | 4.15 | 8.91 | 39.9 |
| Twin #1 | 386 | 9.8 | 2.16 | 4.25 | 20.4 |

[a] Quadratic mean d.b.h.
[b] Mean d.b.h. of largest 40 trees (by d.b.h.) per acre.
[c] Estimated height corresponding to D40.

counted by size class and species on a subplot (1/100 acre for saplings greater than 4.5 feet in height and less than 1.0 inch d.b.h. and 1/300 acre for seedlings shorter than b.h.) located 40 feet from the northeast corner of the main tree measurement plot. A sample of each size class and species was taken outside the plot for age determination. Presence of mammals, birds, insects, and diseases was recorded. Local site conditions, location, and other vegetation and environmental variables were documented.

**Remeasurement schedule—**Plots are remeasured after the growing season on a 5-year measurement cycle. As of 1998, 3 of the 18 installations had only the initial measurement, 15 had one remeasurement available, and 4 of these 15 had two remeasurements completed.

## Results

### Initial Conditions

Estimated total stand ages at establishment ranged from 14 to 41 years. Elevations ranged from a low of 3,000 feet (Bonidu) to 4,500 feet (Alpine #4). The dominant plant associations for each of the 18 installations are shown in table 2. Abbreviations used for tree species names and plant associations are given in table 3.

Pretreatment installation values (based on the untreated plots) for trees per acre, basal area, quadratic mean diameter (QMD), and mean diameter and height of the largest 40 trees per acre (all species combined) are presented in table 4. Initial trees per acre (excluding trees less than 0.6-inch d.b.h., some of which became leave trees) ranged from a low of 386 trees per acre at Twin #1 to a high of 2,716 trees per acre at Cumberland Creek. Basal area per acre ranged from 10 square feet at Twin #1 to 180 square feet at Crevice Creek and Evans Creek. Mean diameter of the largest 40 trees per acre (by diameter) of all species ranged from 3.9 inches at Cabin #2 to 10.2 inches at Crevice Creek. Height of the largest 40 trees per acre (by diameter, all species) ranged from 18 feet at Cabin #2 to 53 feet at Evans Creek.

### Postthinning Conditions

Prethinning and postthinning basal areas, by species, are shown in table 5. In most cases, shifts in overall species composition caused by the thinning treatments were minor.

### Changes in Understory Vegetation

The understory of shrub species has generally responded to release, with density and height of shrub species increasing as spacing increased. This is especially evident at Iron Mountain, Memaloose Lake, and Dog Creek. In plant associations having huckleberry as a major component, the increased vigor of the huckleberry means increased berry production, beneficial to both human users and wildlife. In some other associations, such as those with a major rhododendron component, benefits are less obvious, although thinned stands certainly represent a different environment for wildlife. These dense shrub understories probably do inhibit tree growth to some degree; the overall study provides no means of evaluating this.

At this writing, 5- and 10-year ground vegetation remeasurements are available for the Cumberland, Crevice Creek, Rattrap Pass, and Iron Mountain installations. Tree cover, understory cover, and seedling counts are summarized in table 6. Biodiversity measurements are summarized in table 7. Values were highly variable among plots, and overall means seem more meaningful than a detailed breakdown by installation.

**Table 5—Mean percentage composition by species of thinned plots in the true fir-hemlock spacing study, by installation, pretreatment, and posttreatment**

| | Pretreatment | | | | Posttreatment | | | |
|---|---|---|---|---|---|---|---|---|
| Installation | ABAM[a] | ABPR[b] | TSHE[c] | Other | ABAM | ABPR | TSHE | Other |
| | *Percent of total basal area* | | | | | | | |
| Alpine #4 | 58.6 | 38.6 | 1.4 | 1.4 | 41.7 | 56.7 | -- | 1.6 |
| Bonidu | 65.4 | -- | 32.0 | 2.6 | 72.3 | -- | 26.2 | 1.5 |
| Cabin #2 | 1.6 | 86.4 | .5 | 11.5 | 1.5 | 92.0 | -- | 6.5 |
| Cat Creek | 75.0 | 4.3 | 2.1 | 18.6 | 80.4 | 10.7 | 4.1 | 4.8 |
| Crevice Creek | 24.5 | -- | 73.9 | 1.6 | 27.6 | -- | 72.3 | .1 |
| Cumberland | 63.5 | -- | 33.4 | 3.1 | 59.5 | -- | 40.5 | -- |
| Dog Creek | -- | 66.0 | 26.5 | 7.5 | -- | 70.2 | 26.3 | 3.5 |
| Evans Creek | 80.2 | .2 | 12.3 | 7.3 | 82.8 | .1 | 10.9 | 6.2 |
| Haller Pass | -- | 91.8 | .7 | 7.5 | -- | 94.6 | .2 | 5.2 |
| Iron Mountain | 84.6 | -- | 14.2 | 1.2 | 86.4 | -- | 13.0 | .6 |
| Job #2 | 9.3 | 80.5 | .1 | 10.1 | 4.5 | 90.6 | -- | 4.9 |
| Marys Creek | 3.3 | 67.1 | 11.4 | 17.9 | 1.7 | 80.1 | 5.4 | 12.8 |
| Memaloose | 5.4 | 93.5 | .3 | .8 | 9.4 | 90.6 | -- | -- |
| North Mountain #2 | 66.1 | 2.0 | 12.9 | 19.0 | 71.3 | 2.1 | 12.5 | 14.1 |
| Pointer #3 | 31.2 | 66.7 | .2 | 1.9 | 14.5 | 85.2 | .3 | -- |
| Rattrap Pass | 11.0 | -- | 82.5 | 6.5 | 12.0 | -- | 86.3 | 1.7 |
| Tonga Ridge | 83.7 | 11.7 | 4.3 | .3 | 83.2 | 14.7 | 2.1 | -- |
| Twin #1 | 1.3 | 82.9 | .4 | 15.4 | .9 | 90.4 | .1 | 8.6 |

[a] *Abies amabilis.*
[b] *Abies procera.*
[c] *Tsuga heterophylla.*

**Table 6—Summary of tree cover, understory cover, and seedling counts on ecology subplots at the Iron Mountain (2 replicates), Crevice Creek, Rattrap Pass, and Cumberland installations of the true fir-hemlock spacing study, prethinning and at 5-year and 10-year remeasurements**

| | | | | Tree cover | | | Understory cover | | | Seedling number[a] | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Spacing | Plot size | Basis, no. of plots | Leave trees | Prethin. | 5-year | 10-year | Prethin. | 5-year | 10-year | Prethin. | 5-year | 10-year |
| *Feet* | *Acres* | | *No./acre* | | | *Percent* | | | | | *Per acre* | |
| No treatment | 0.200 | 5 | 2715 | 73.0 | 90.0 | 89.6 | 58.0 | 33.0 | 37.0 | 2004 | 4360 | 1880 |
| 7.9 | .242 | 5 | 632 | 67.0 | 75.0 | 89.6 | 68.0 | 71.0 | 41.6 | 5172 | 2480 | 3060 |
| 10.1 | .234 | 5 | 410 | 74.0 | 77.0 | 78.2 | 40.0 | 72.0 | 68.8 | 2920 | 1340 | 2440 |
| 12.8 | .241 | 5 | 261 | 72.8 | 56.0 | 72.0 | 56.4 | 70.6 | 78.2 | 4580 | 4440 | 11640 |
| 16.4 | .302 | 5 | 161 | 67.6 | 41.0 | 52.0 | 61.8 | 80.6 | 85.0 | 1548 | 1472 | 3980 |
| 20.9 | .361 | 5 | 99 | 67.4 | 31.0 | 41.0 | 62.0 | 78.2 | 86.0 | 4060 | 1780 | 3720 |
| Means, thinned plots only | | 25 | | 69.8 | 56.0 | 66.6 | 57.6 | 74.5 | 71.9 | 3656 | 2302 | 4968 |

[a] Includes small saplings <1.0 inch d.b.h.

**Table 7–Means of combined biodiversity measurements on all ecology subplots, by treatments, at the Iron Mountain, Crevice Creek, Rattrap Pass, and Cumberland Creek installations of the true fir-hemlock spacing study**

| | | | Tree species present | | | Ground species present | | | Cryptogam species present | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Treatment | Spacing | Basis, no. of plots | Prethin. | 5-year | 10-year | Prethin. | 5-year | 10-year | Prethin. | 5-year | 10-year |
| | *Feet* | | - - - - - | - - - - - | - - - - - | - - - - - | *Number* | - - - - - | - - - - - | - - - - - | - - - - - |
| Untreated plots | NT[a] | 5 | 3.8 | 3.8 | 3.2 | 26.8 | 27.0 | 22.2 | 8.2 | 18.4 | 28.6 |
| Thinned plots | 7.9 | 5 | 4.8 | 4.2 | 3.8 | 26.2 | 26.6 | 26.4 | 7.8 | 19.0 | 28.0 |
| | 10.1 | 5 | 4.0 | 3.6 | 4.0 | 21.4 | 24.4 | 25.8 | 10.0 | 22.4 | 26.2 |
| | 12.8 | 5 | 5.0 | 4.2 | 4.0 | 19.8 | 23.2 | 23.6 | 9.4 | 18.6 | 27.2 |
| | 16.4 | 5 | 3.6 | 3.8 | 3.6 | 28.0 | 26.6 | 31.0 | 13.0 | 17.6 | 29.0 |
| | 20.9 | 5 | 4.2 | 4.0 | 4.4 | 17.8 | 22.0 | 27.0 | 7.8 | 18.0 | 23.2 |
| Means all thinned plots | | 25 | 4.3 | 4.0 | 4.0 | 22.6 | 24.6 | 26.8 | 9.6 | 19.1 | 26.7 |

[a] NT = no treatment.

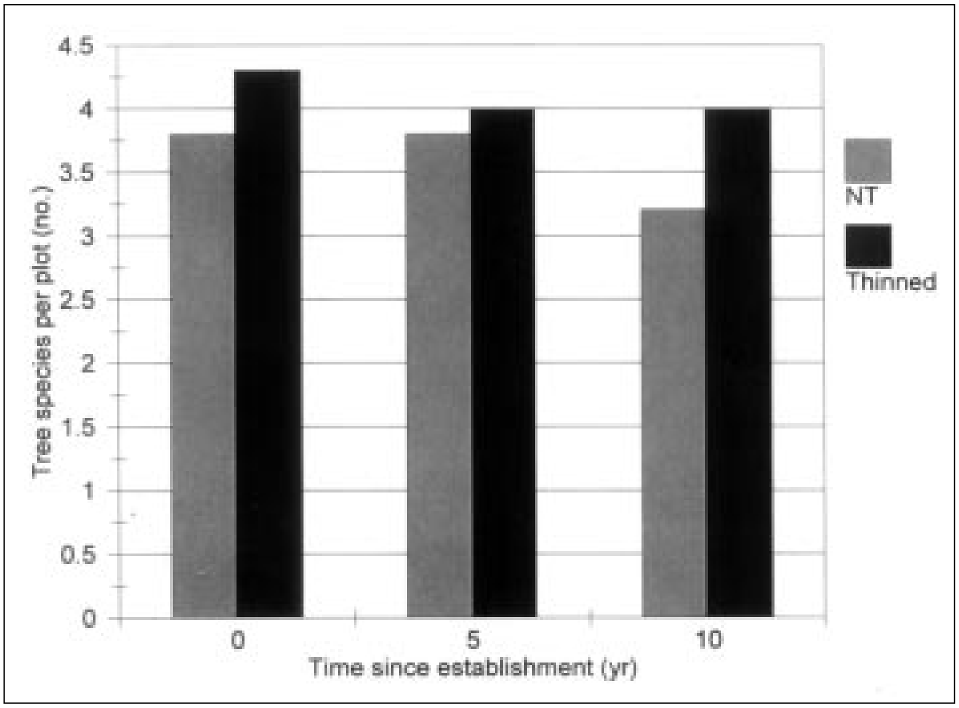


Figure 3–Mean number of tree species recorded, by year and treatment group. NT = no treatment.

**Pretreatment averages–**Initial cover of trees over 1 inch d.b.h. was 66 percent at Iron Mountain, 94 percent at Crevice Creek, 64 percent at Rattrap Pass, 58 percent at Cumberland Creek, and averaged 69.8 percent for thinned plots at the four installations. Cover of ground vegetation species (shrubs and herbs) was 64 percent at Iron Mountain (two replicates), 10 percent at Crevice Creek, 68 percent at Rattrap, and 83 percent at Cumberland, with an average of 57.6 percent for thinned plots at the four installations. Numbers of seedlings and saplings per acre (past the germinant stage and less than 1 inch d.b.h.) at these four installations were 3,300, 5,688, 2,692, and 3,300, respectively; average, 3,656.

**Postthinning changes–**Five-year remeasurements compared to prethinning values (table 6) show that, as expected, tree cover went down proportionately to severity of treatment but increased 17 percent in the untreated plots. During the second growth period, tree cover in the thinned plots increased from 56 percent to 66 percent, while tree cover in the control plots remained steady at 90 percent. During the first 5 years, the cover of ground vegetation declined sharply in the unthinned plots but increased 17 percent in thinned plots, declining slightly during the second growth period. Cover of shrubs generally showed a greater response in the more moderately thinned plots. The number of seedlings and small saplings increased during the first growth period in the unthinned plots and decreased in the thinned plots. During the second growth period, the reverse was true, with numbers declining in the unthinned plots and increasing dramatically in the treated plots.

Posttreatment results for tree, ground vegetation, and cryptogram biodiversity (table 7 and fig. 3) show that the number of tree species declined slightly over the 10-year

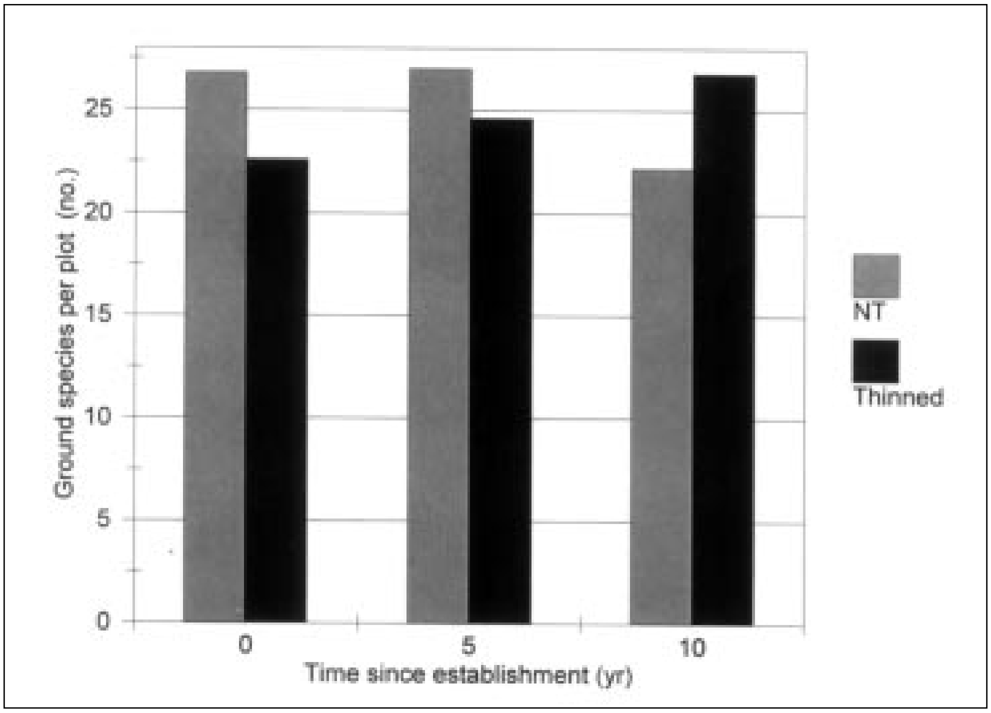


Figure 4–Mean number of understory species recorded, by year and treatment group. NT = no treatment.

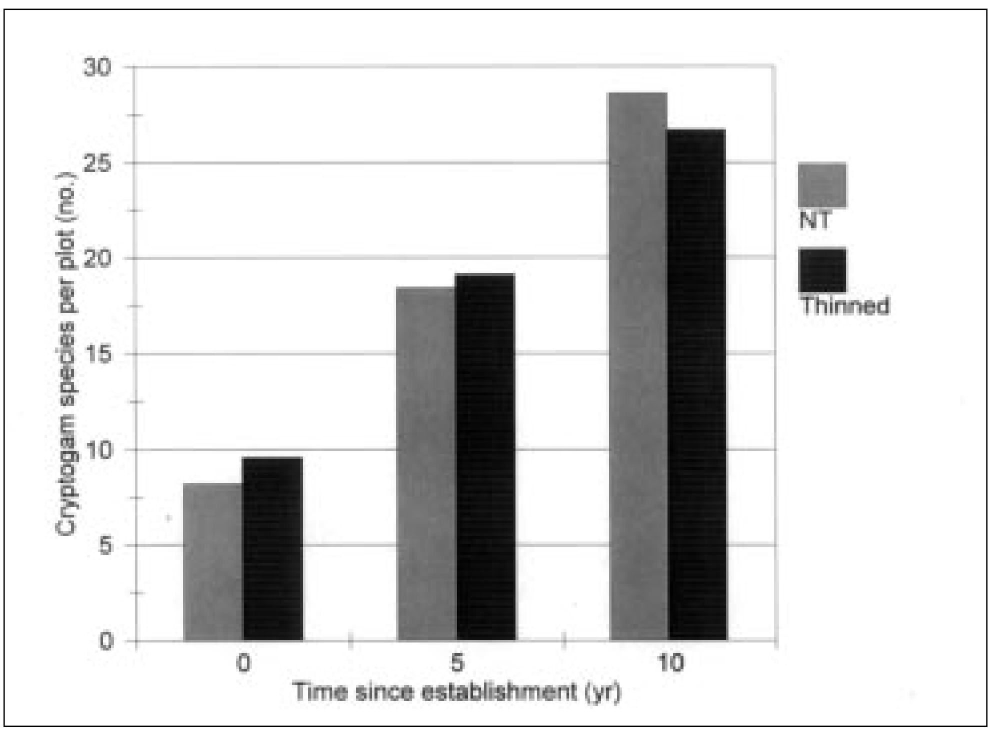


Figure 5–Mean number of cryptogam species recorded, by year and treatment group. NT = no treatment.

observation period in most treatments, including the unthinned plots. The number of shrub and herb species present decreased in the unthinned plots and increased in the thinned plots (fig. 4). Cryptogams (mosses, lichens, liverworts) showed the greatest increase in diversity, and increased sharply in the unthinned as well as in the thinned plots (fig. 5); the number of cryptogam species more than doubled during the 10-year period. There was a several-fold increase in the number of epiphytic cryptogams. At time of plot establishment, few if any epiphytes were recorded. Ten years later, an average of more than five species of epiphytes were present.

## Mortality

Mortality for the 5-year period was slight, with no clear relation to spacing. Percentages of initial number of trees (after treatment) dying during the 5-year period were, by treatment:

| Treatment | Mortality |
|---|---|
| | *Percent* |
| No treatment | 2.3 |
| 7.9-ft spacing | 1.3 |
| 10.1-ft spacing | 1.2 |
| 12.8-ft spacing | 1.1 |
| 16.4-ft spacing | .5 |
| 20.9-ft spacing | 1.5 |

## Tree Growth in Relation to Spacing

This study differs from spacing studies conducted in single-species stands in that stands differ widely in species composition, although all include one or more of the three species of interest. Separate analyses by individual species seem most meaningful for variables such as height increment and diameter increment, which are expected to differ among species.

For each species, 5-year response was analyzed for (1) all stems of the species and (2) those stems of the species that were included in the largest 100 stems per acre (all species combined). One hundred per acre was chosen as the basis for “top height trees,” rather than the more common 40 per acre, because 40 per acre frequently gives too few sample trees per plot to provide stable averages for an individual species, and because 100 per acre is the expected number of leave trees at the widest spacing. Number of sample trees per species per plot had a possible range from 0 to about 30 for trees included in the 100 largest per acre, and from 0 to 100 or more for all trees. With this wide variation in sample size per plot, weighted analyses seemed appropriate. Weights used in the following analyses were $w = N^{1/2}$, where N is the number of trees of a given species included in the sample.

Response was analyzed for each species for four basic variables: (1) periodic annual increment (PAI) in height of the largest 100 trees per acre (H100), (2) PAI in diameter of the largest 100 trees per acre (D100), (3) PAI in height of all trees (Hall), and (4) PAI in diameter of all trees (Dall). Response values are expressed as arithmetic means of periodic annual increment of survivors, for the variable and species indicated.

**Table 8–Fit statistics for regressions of PAI on installation and spacing, true fir-hemlock spacing trials, 5-year measurements**

| | | | Regression on spacing or 1/spacing only | | Regression on installations[a] only | | Regression on installations + spacing (or 1/spacing) | |
|---|---|---|---|---|---|---|---|---|
| Variable | Species | Basis, no. of plots | $R^2$ | p | $R^2$ | p | $R^2$ | p for spacing |
| PAI in H100[b] | ABAM[c] | 48 | 0.07 | 0.08 | 0.72 | 0.0001 | 0.78 | 0.002 |
| | ABPR[d] | 41 | .07 | .09 | .62 | .0001 | .73 | .002 |
| | TSHE[e] | 42 | -- | >.4 | .81 | .0001 | .82 | .22 n.s. |
| PAI in Hall | ABAM | 48 | -- | >.4 | .84 | .0001 | .84 | >.4 n.s. |
| | ABPR | 41 | .02 | .36 | .75 | .0001 | .76 | .37 n.s. |
| | TSHE | 42 | .05 | .15 | .86 | .0001 | .88 | .023 |
| PAI in D100[f] | ABAM | 48 | .08 | .06 | .73 | .0001 | .82 | .0001 |
| | ABPR | 41 | .05 | .14 | .77 | .0001 | .81 | .009 |
| | TSHE | 42 | .10 | .04 | .70 | .0001 | .78 | .002 |
| PAI in Dall[g] | ABAM | 48 | .28 | .0001 | .57 | .0001 | .87 | .0001 |
| | ABPR | 41 | .35 | .0001 | .43 | .009 | .76 | .0001 |
| | TSHE | 42 | .39 | .0001 | .57 | .0001 | .87 | .0001 |

n.s. = nonsignificant.
[a] Installations are represented as dummy (0,1) variables.
[b] Mean height of largest 100 per acre.
[c] *Abies amabilis.*
[d] *Abies procera.*
[e] *Tsuga heterophylla.*
[f] Average diameter of largest 100 per acre.
[g] Average diameter of all trees.

**Graphic comparisons of tree growth by spacing—**For each of the three species, we made comparisons in terms of weighted means for each treatment of (1) PAI in D100, (2) PAI in Dall, (3) PAI in H100, and (4) PAI in Hall.

As would be expected, the graphs show clear trends of diameter increment with spacing (figs. 6-11). The graphs appear to indicate a depression of height growth at wide spacings for Pacific silver fir and possibly for noble fir, with little indication of such an effect for western hemlock (figs. 12-17). Comparisons of similar graphs for individual installations show great variation within species and treatments.

The "no treatment" plots are widely variable in stocking and cannot be directly compared with "treated" plots. The means do indicate that diameter growth of all trees and of the largest 100 per acre and height growth of all trees are less for the "no treatment" plots than for treated plots. Some "no treatment" plots are not yet undergoing severe competition, and we expect these differences to become greater as stands close in and competition intensifies. Height growth of the largest 100 per acre appears greater on "no treatment" plots than on spaced plots for silver fir and noble fir, although there is little difference for western hemlock.

**Regressions on spacing—**We ran simple weighted regressions ($w = N^{1/2}$) for each response variable and species that used as the predictor either spacing or 1/spacing. Unthinned plots were excluded, because there is no satisfactory way to express "no treatment" in terms of spacing. Data were excluded for any installation having fewer than four plots with observations for the species in question. For PAI in diameter, spacing clearly had an effect; for PAI in height, it was nonsignificant. The coefficient of determination ($R^2$) values were very low (table 8).

**Regressions on spacing and installation—**There are obvious differences in site quality among installations, although we do not have calculated site index values for these young stands. There also were considerable differences in stage of stand development at the time plots were established.

We ran a series of weighted regressions in which installations were coded as dummy variables (Di), separately by species and dependent variable. Di takes value "1" for observations on installation "i"; otherwise, "0."

1. Installations only:

$$PAI = \sum b_i D_i ,$$

where $D_i$ is the set of dummy variables (0,1) representing installations.

2. Installations + spacing:

$$PAI = \sum b_i D_i + c \text{ (spacing) , or}$$

$$PAI = \sum b_i D_i + c \text{ (1/spacing) .}$$

*(Text continues on p. 27.)*

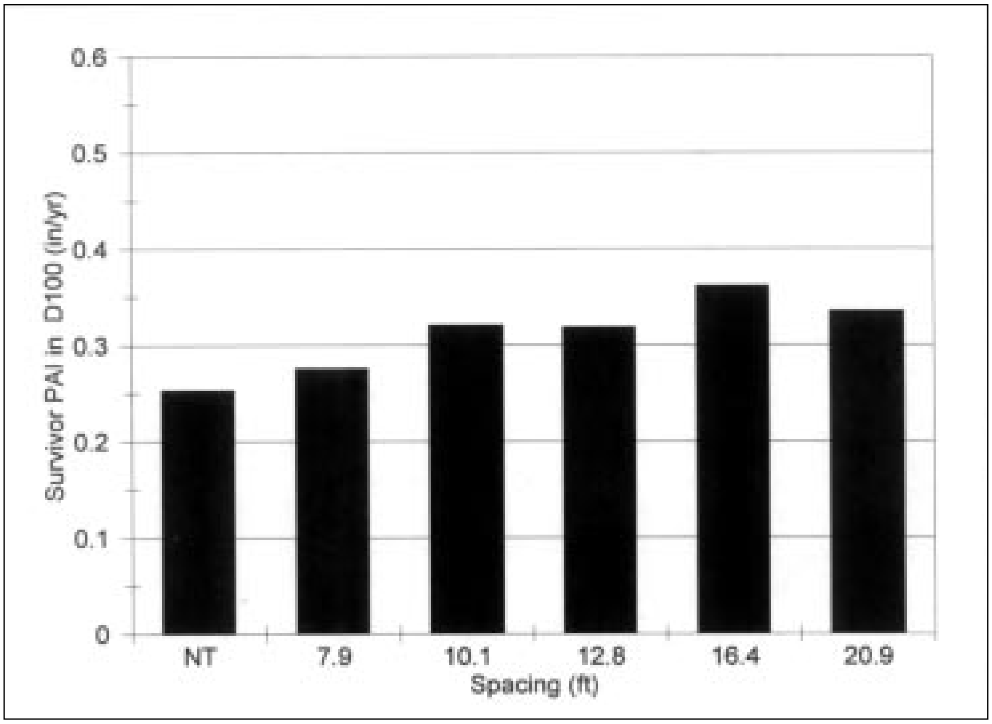


Figure 6—Means of 5-year periodic annual diameter increment of trees included in the largest 100 Pacific silver fir per acre surviving at the 5-year measurement, by spacing. NT = no treatment.

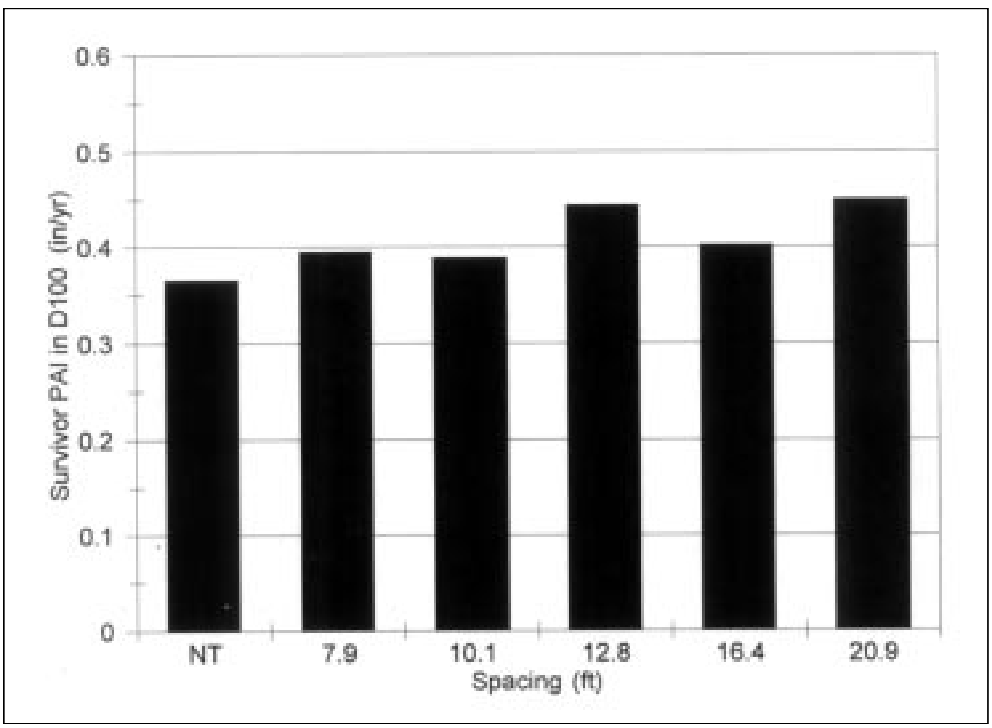


Figure 7–Means of 5-year periodic annual diameter increment of trees included in the largest 100 noble fir per acre surviving at the 5-year measurement, by spacing. NT = no treatment.

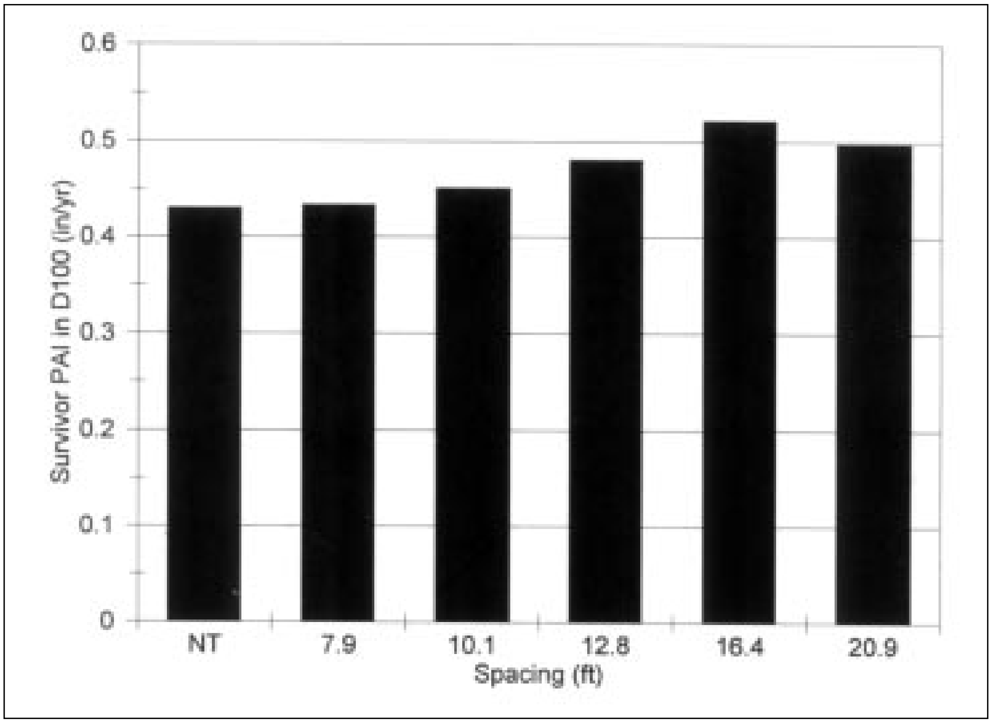


Figure 8–Means of 5-year periodic annual diameter increment of trees included in the largest 100 western hemlock per acre surviving at the 5-year measurement, by spacing. NT = no treatment.

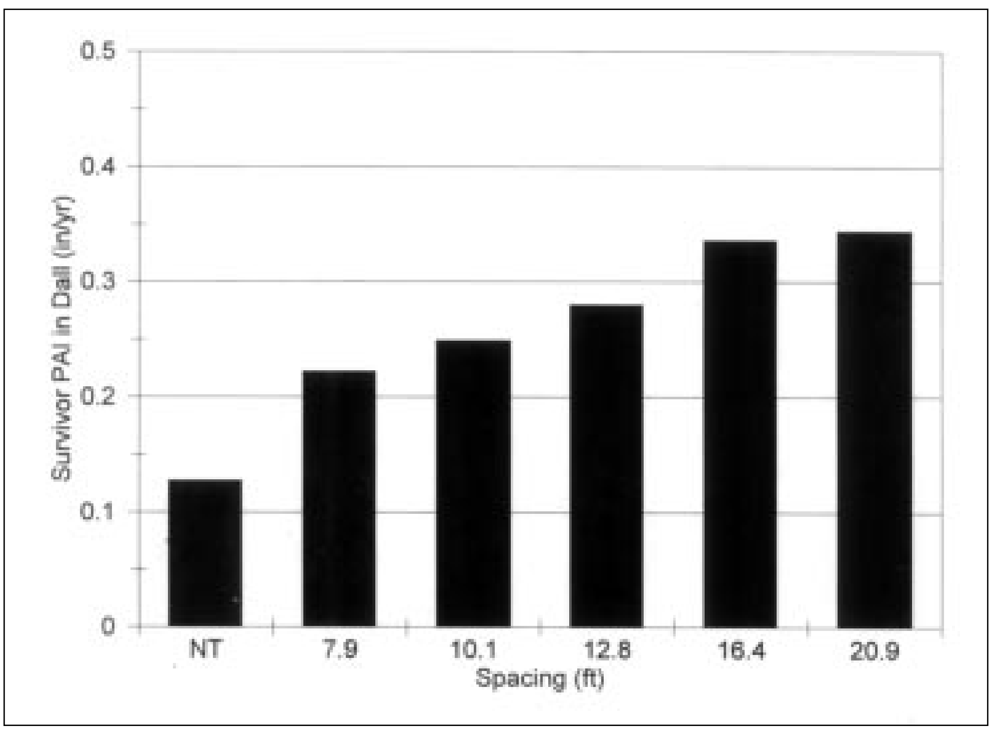


Figure 9–Means of 5-year periodic annual diameter increment of all Pacific silver fir trees surviving at the 5-year measurement, by spacing. NT = no treatment.

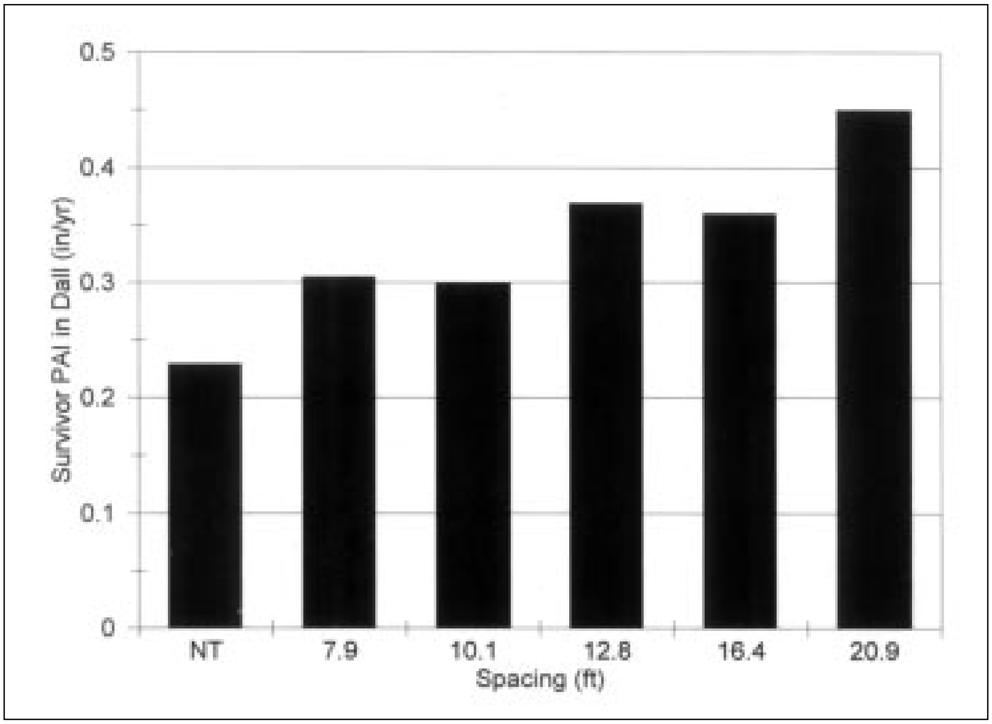


Figure 10–Means of 5-year periodic annual diameter increment of all noble fir trees surviving at the 5-year measurement, by spacing. NT = no treatment.

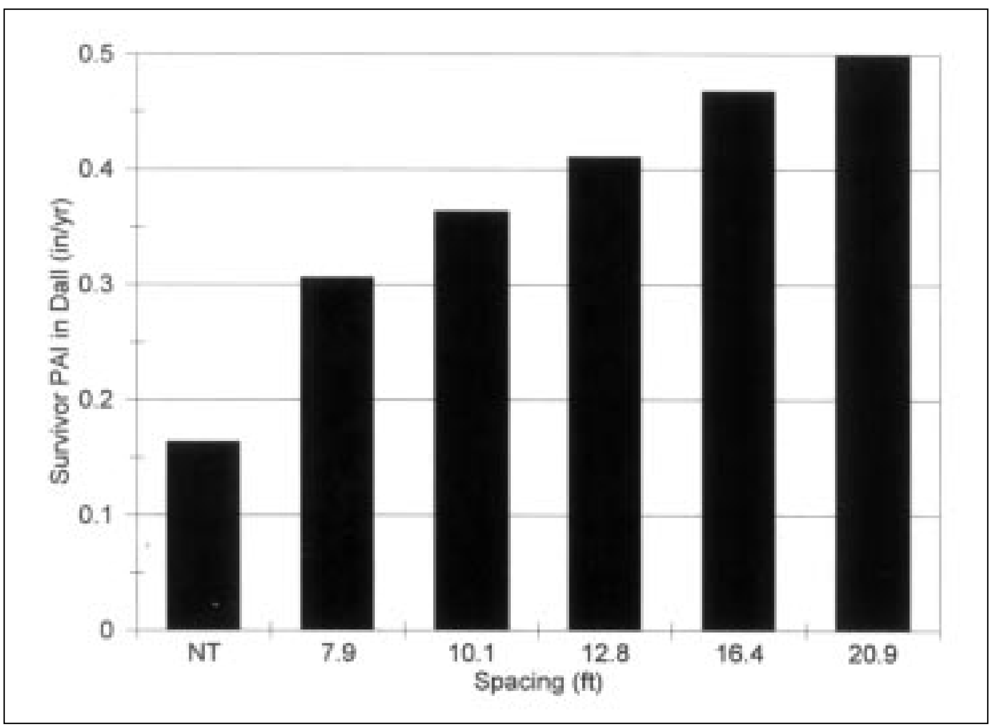


Figure 11–Means of 5-year periodic annual diameter increment of all western hemlock trees surviving at the 5-year measurement, by spacing. NT = no treatment.

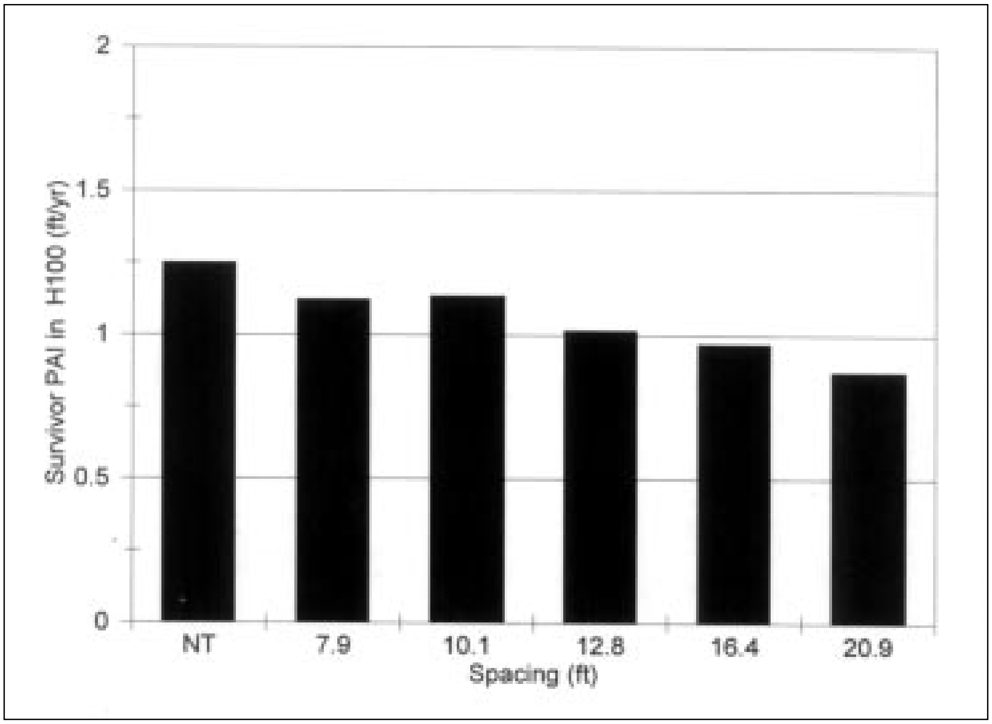


Figure 12–Means of 5-year periodic annual height increment of trees included in the largest 100 Pacific silver fir per acre surviving at the 5-year measurement, by spacing. NT = no treatment.

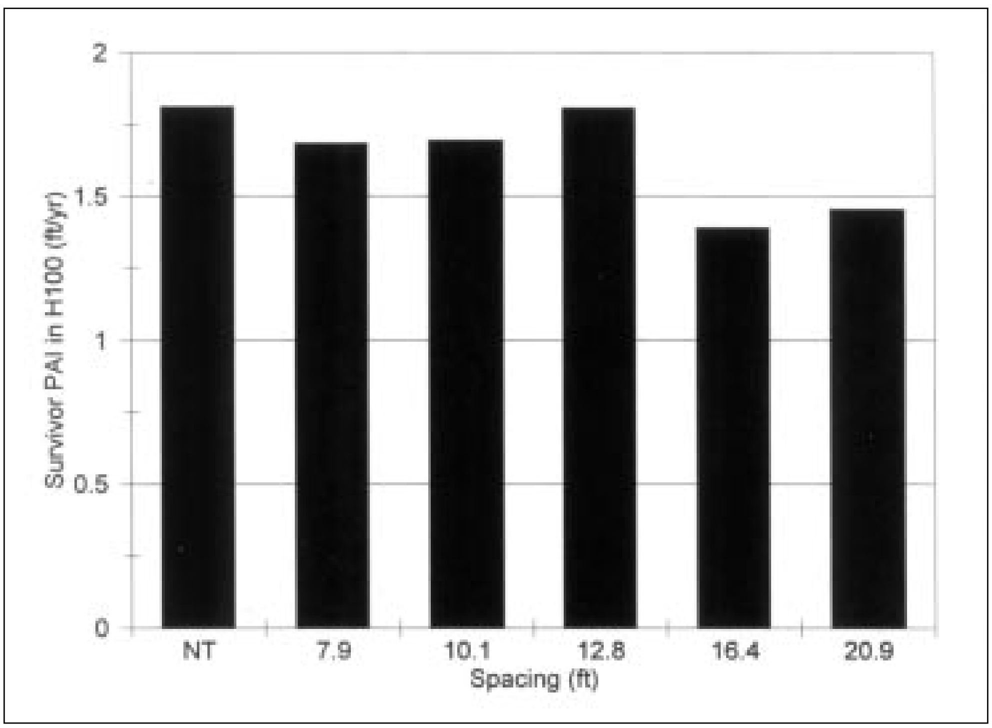


Figure 13–Means of 5-year periodic annual height increment of trees included in the largest 100 noble fir per acre surviving at the 5-year measurement, by spacing. NT = no treatment.

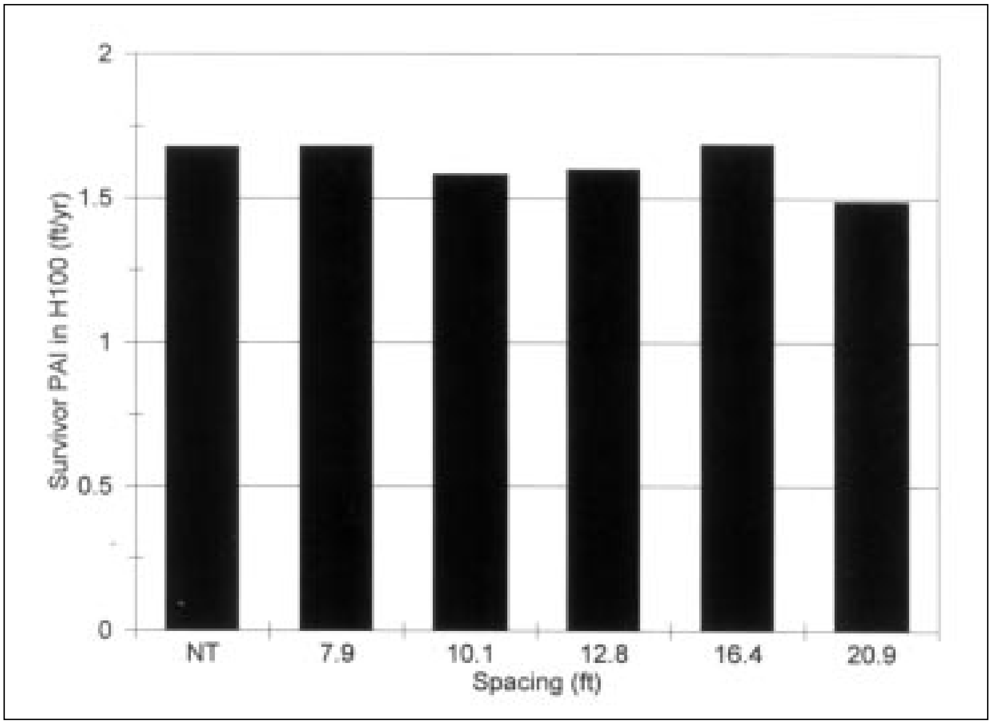


Figure 14–Means of 5-year periodic annual height increment of trees included in the largest 100 western hemlock per acre surviving at the 5-year measurement, by spacing. NT = no treatment.

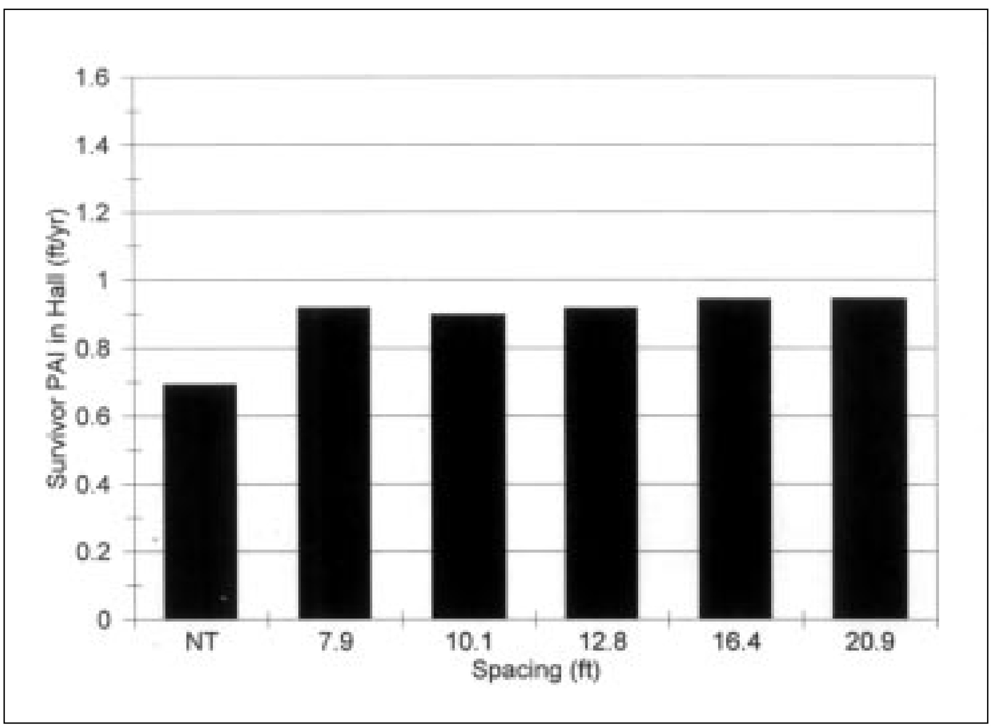


Figure 15–Means of 5-year periodic annual height increment of all Pacific silver fir trees surviving at the 5-year measurement, by spacing. NT = no treatment.

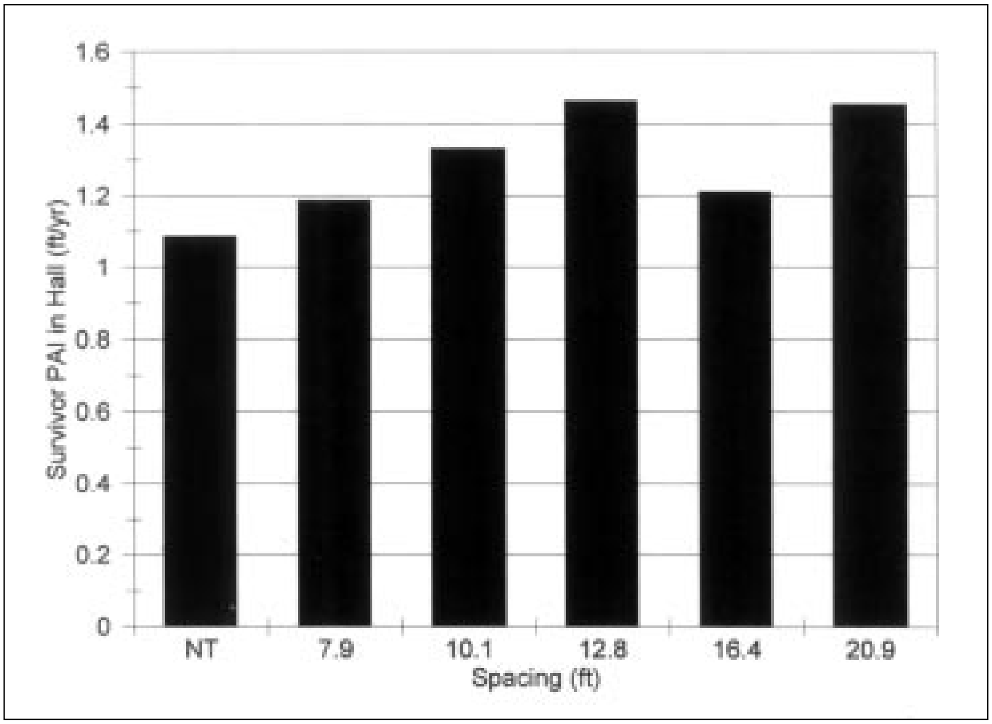


Figure 16–Means of 5-year periodic annual height increment of all noble fir trees surviving at the 5-year measurement, by spacing. NT = no treatment.

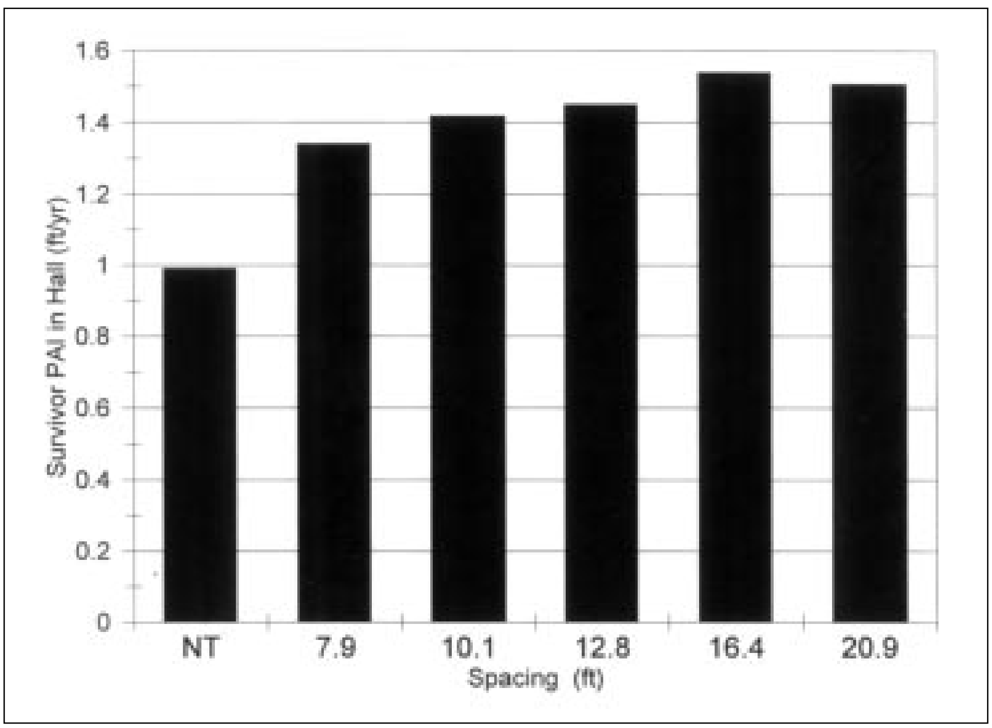


Figure 17–Means of 5-year periodic annual height increment of all western hemlock trees surviving at the 5-year measurement, by spacing. NT = no treatment.

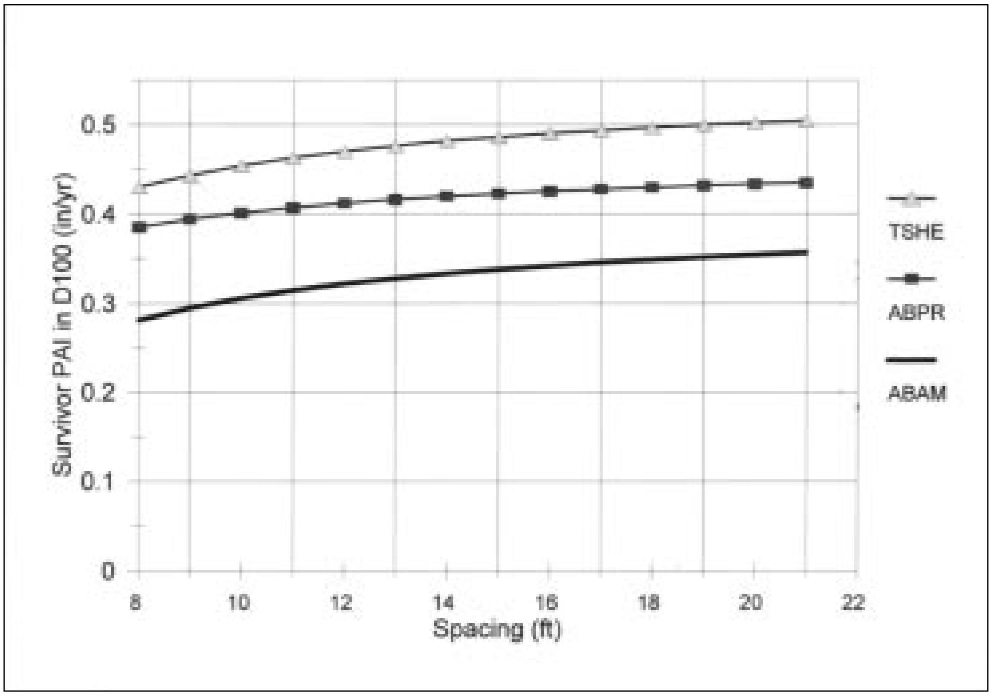


Figure 18–Regression estimates of 5-year periodic annual diameter increment of all trees included in the largest 100 per acre, by species and spacing.

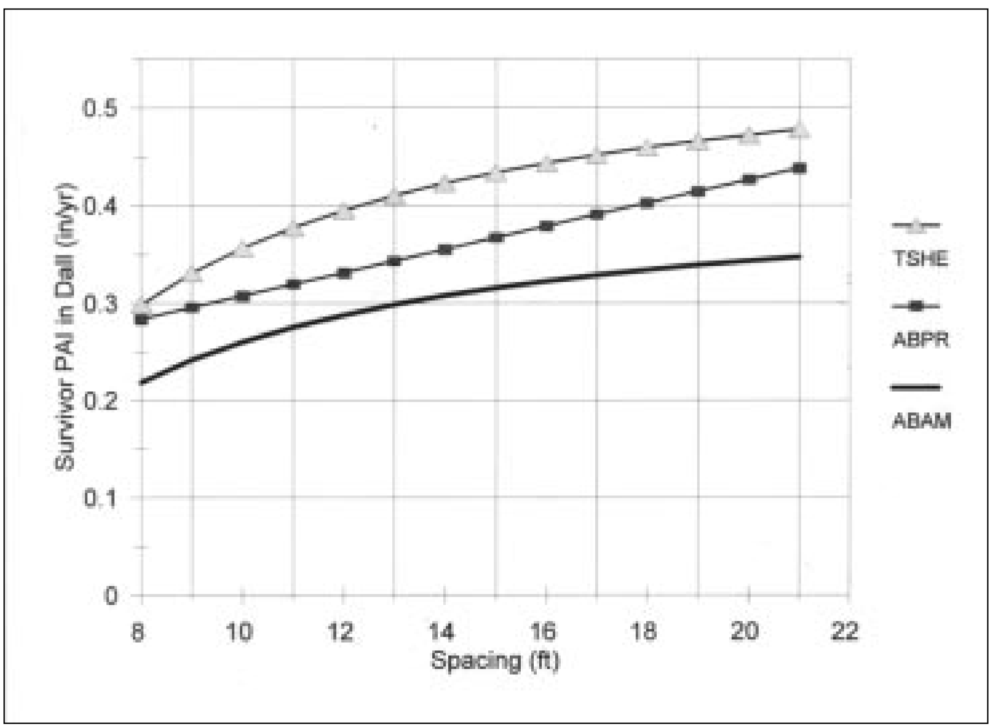


Figure 19–Regression estimates of 5-year periodic annual diameter increment of all trees, by species and spacing.

First, the set of all dummy variables was forced into the regression. This accounted for a large fraction of the variation.

The stepwise procedure was used to choose between "spacing" and "1/spacing" as an additional variable. Improvements in $R^2$ due to the addition of spacing were substantial. The spacing variable was significant or highly significant in 9 of the 12 regressions. Cases where it was not significant were PAI-Hall for silver fir and noble fir, and PAI-H100 for hemlock (table 8).

Figures 18-21 are based on these regressions, with elevations adjusted to pass through species means. Results for diameter growth are as expected. A result of considerable interest, however, is that in silver fir and noble fir, height growth of the largest 100 trees per acre seems to be depressed at the wider spacings (fig. 20). There is no evidence of such an effect for western hemlock. Analogy with experience with Douglas-fir on relatively poor sites (e.g., Harrington and Reukema 1983) suggests that this height growth depression (often termed "thinning shock") is probably temporary and may be followed by accelerated growth in later growth periods. It probably should be viewed as a redistribution of growth between height and diameter in response to change in the tree's environment.

There is no apparent relation between height growth of all trees and spacing (fig. 21). This does not necessarily mean that height growth of all trees is unaffected by spacing. Average diameters of leave trees are greater at wide spacings, and one might anticipate that vigorous trees of large diameter would make greater height growth than those of small diameter. Absence of any apparent effect of spacing therefore would be consistent with some reduction in height growth of trees of given diameter.

## Trends of Height Growth Over Time

Values of H100 were calculated for each installation having a reasonable representation of the given species, as weighted means of H100 across all treatments within the installation. These then were plotted over installation age at b.h. and visually compared with existing site index curves. Comparisons are necessarily inexact, because of the limited age range of the available data and because H100 does not correspond exactly to the stand component used in construction of the site index curves to which they are compared.

**Pacific silver fir—**Trends are shown in figure 22. The dashed line represents the height over age curve for site 130 (base age 100 b.h.) from Hoyer and Herman (1989), which passes through the approximate mean of the data. Results are consistent with the comparisons (based on stem analyses of young trees) of Murray and others (1991), in that heights are considerably greater than the mean of Hoyer and Herman's data (which ranges approximately from site 45 to 145); and that–so far as can be judged from these very limited data–trends appear to be more or less proportional to their curves.

**Noble fir—**Similar plots for noble fir (fig. 23) also are consistent with earlier comparisons (Murray and others 1991). Observed trends are grouped around the upper margin of Herman and others' (1978) family of curves, with mean approximately corresponding to their site 160 (100-year b.h. base age). This is close to the maximum in

*(Text continues on p. 30.)*

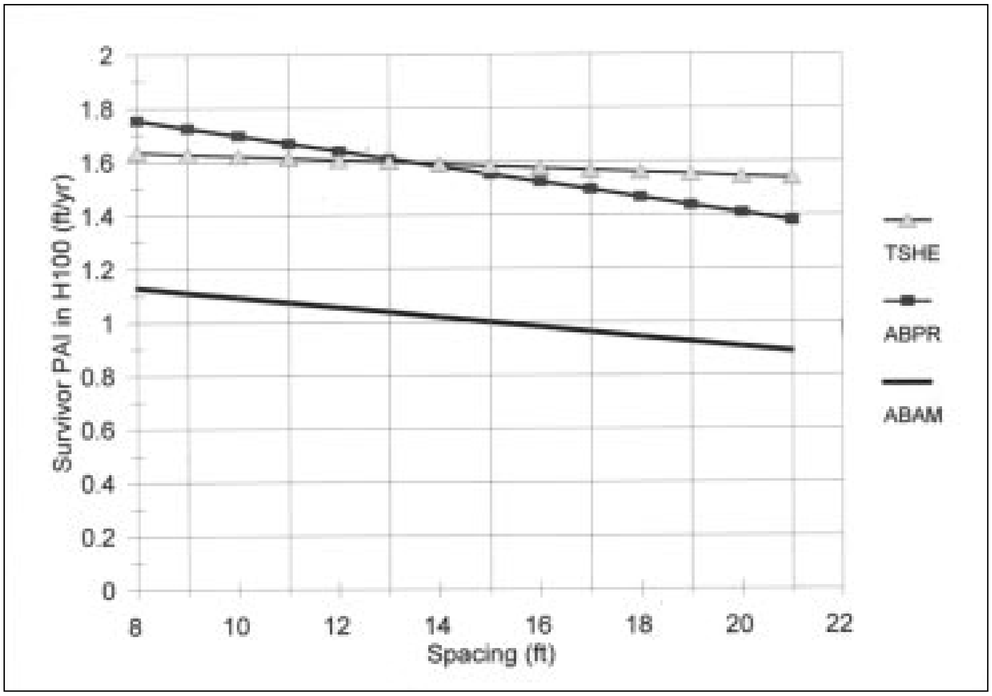


Figure 20–Regression estimates of 5-year periodic annual height increment of all trees included in the largest 100 per acre, by species and spacing.

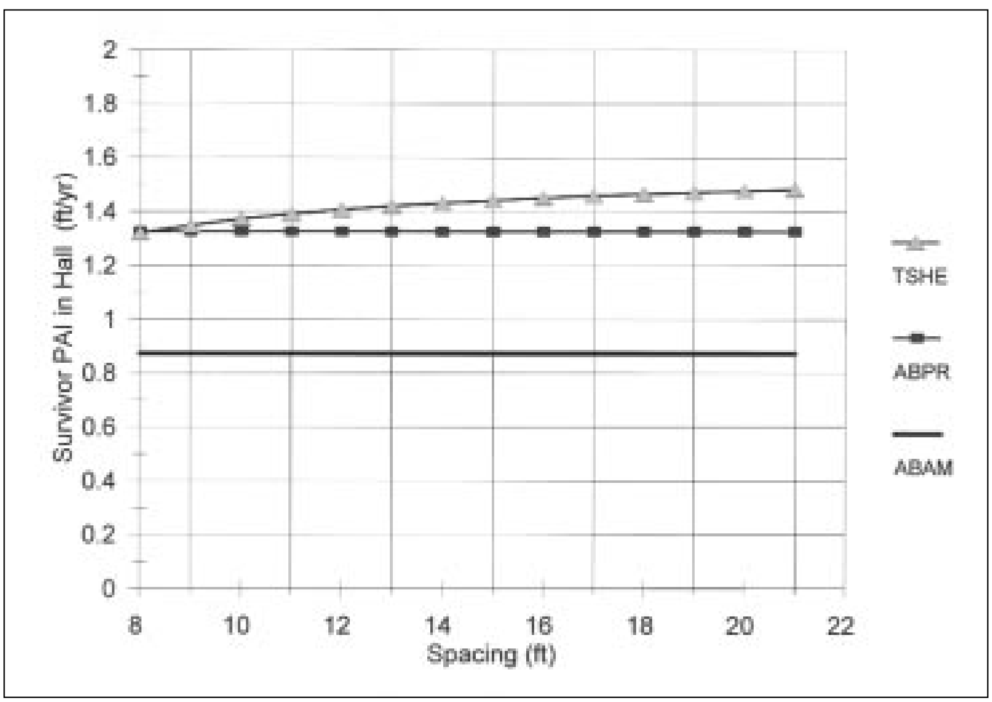


Figure 21–Regression estimates of 5-year periodic annual height increment of all trees, by species and spacing.

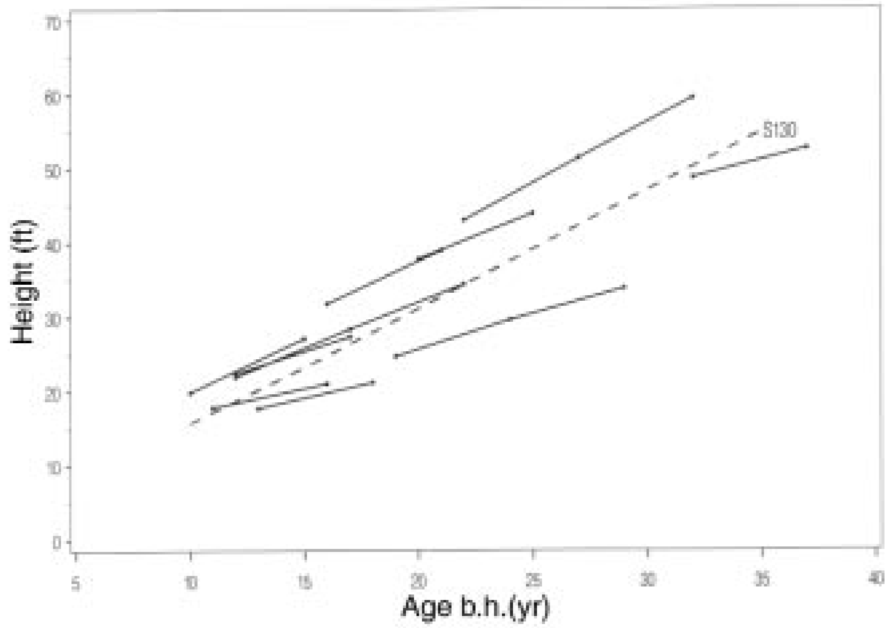


Figure 22–Observed height growth of the largest 100 trees per acre for Pacific silver fir, compared with Hoyer and Herman’s (1989) curve for site index 130.

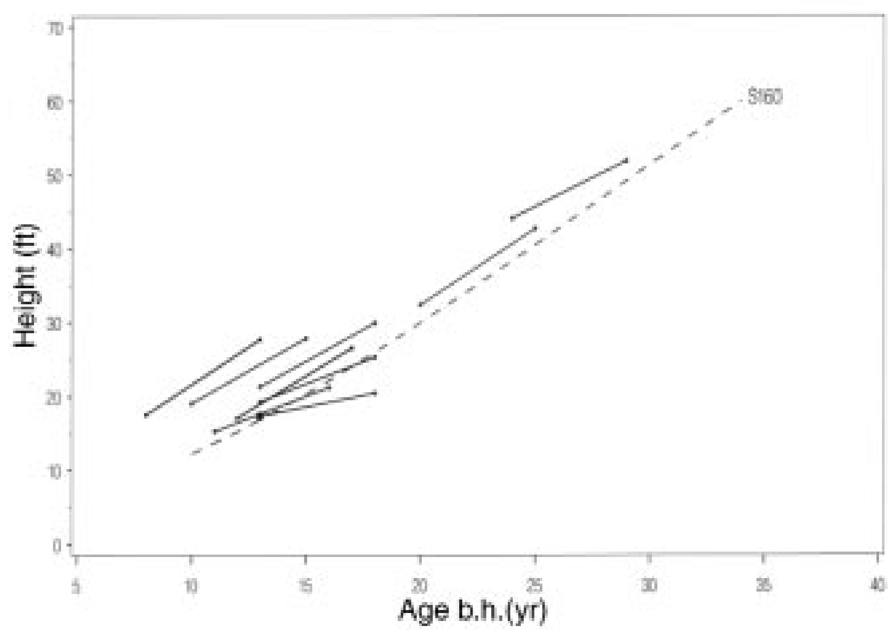


Figure 23–Observed height growth of the largest 100 trees per acre for noble fir, compared with Herman and others’ (1978) curve for site index 160.

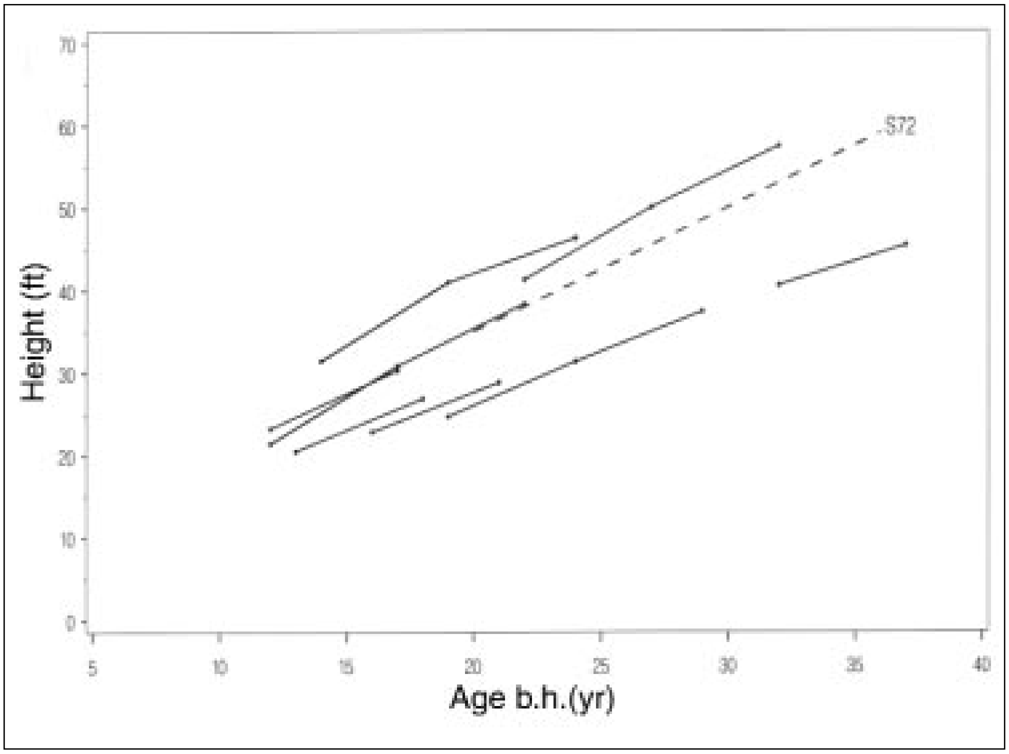


Figure 24–Observed height growth of the largest 100 trees per acre for western hemlock, compared with Wiley's (1978b) curve for site index 74.

Herman's data, which ranged from about site 50 to 180. Our trees were from harvested areas, which generally did not include the poorest sites. It therefore is not surprising that heights are greater than the mean in the data from Herman and others. However, there also seem to be pronounced differences in slope, thereby indicating that our stands have made much more rapid early growth than did the old trees used in Herman's analyses. One can speculate that the differences may be partly a matter of biases inherent in the stem analysis procedure of constructing curves from very old trees, possible changes in climatic conditions over time, and–very probably–the fact that many of our trees were from plantations with relatively little early vegetative competition.

**Western hemlock—**Similar plots (fig. 24) seem to be in reasonable agreement with Wiley's (1978b) curve for site 72 (50-year b.h. base age). As might be expected, the site 72 curve is well below the average site index of Wiley's data (range 60 to 130), which were from low-elevation stands.

## Conclusions

One 5-year period is obviously far too short to provide much in the way of conclusions. Some preliminary observations can be made, however:

1. Comparative growth rates are in the order, silver fir < noble fir < western hemlock. These comparisons do not provide good estimates of the magnitude of the differences, because not all species occur at all installations, and means and regressions for each of the three species therefore represent different subsets of the 15 installations currently available.

2. In general, diameter growth is more strongly related to spacing than is height growth; this is expected. Diameter growth of both all trees and those trees included in the largest 100 per acre increased with spacing.

3. In silver fir and noble fir, height growth of the largest 100 trees per acre seems to be depressed at the wider spacings. There is no evidence of such an effect for western hemlock.

4. The "no treatment" plots are widely variable in stocking and cannot be directly compared with the "treated" plots. The means indicate that diameter growth of all trees and of the largest 100 per acre, and height growth of all trees, are less in "no treatment" plots than in thinned plots. Height growth of the largest 100 per acre seems greater in "no treatment" plots than in thinned plots for silver fir and noble fir, little different for western hemlock. This is consistent with the trends mentioned previously of depressed height growth for silver fir and noble fir at wide spacings.

5. Comparisons of height growth trends with existing height growth curves are necessarily limited by the narrow range of ages available as yet but seem to indicate that—
   a. trends for Pacific silver fir and western hemlock appear similar in shape to the existing curves, although H100 growth rates for the silver fir data are near the upper margin of the older data and those for western hemlock near the lower.
   b. trends for noble fir indicate much faster early height growth than do the existing site curves and appear to differ in shape.

6. The understory of shrub species has generally responded to release, with density and height of shrubs increasing as spacing increased. Cover of ground vegetation declined sharply in the unthinned plots but increased in thinned plots. Number of shrub and herb species decreased in unthinned plots while increasing in thinned plots. Cryptogams showed the greatest increase in diversity, increasing sharply in untreated as well as in thinned plots. There was a several-fold increase in number of epiphytic cryptogam species.

## Future of the Study

Though less extensive than originally planned, these installations represent a unique source of information on growth patterns and development of even-aged true fir-hemlock stands at a variety of density levels, whose value will increase rapidly with advancing age. They should be extremely valuable as a part of the more extensive data needed to construct reliable growth and yield models for these species that will be applicable to a range of management regimes.

Although there are no published growth and yield tables for high-elevation true firs in western Oregon and Washington, Schumacher's (1926, 1928) normal yield tables for the closely related white fir (*Abies concolor* (Gord. & Glend.) Lindl. ex Hildebr.) and red fir (*A. magnifica* A. Murr.) in California and observations of existing older stands of noble fir and Pacific silver fir in the Northwest show that some true fir stands can develop extremely high volumes. They characteristically have slow height development in youth followed by a long period of sustained height and volume growth. Hence, long rotations are necessary to capture their productive potential. Although this may be a drawback in terms of the financial criteria traditional in forest economics, many true fir stands can produce high volumes and values. The long rotations necessary to realize these also can enhance compatibility of timber production, recreation, and watershed uses in these high-elevation stands. And the lucrative market for Christmas trees and true fir boughs from young plantations provides early returns that often can pay for early silvicultural operations.

At present we lack quantitative and site-specific information on growth rates, patterns of development, potential yields, and effects of active management. The study reported here is—to our knowledge—the only study of the kind in existence. Without long-term growth data such as this study will provide, there is little factual basis for evaluating the productive potential of high-elevation true fir-hemlock stands under management or for construction of thinning guides or of growth models applicable to any kind of active management. Additionally, these plots provide an opportunity to assess the effects of a wide range of tree densities on composition and growth of understory species. Such relations are particularly important in the upper elevations where huckleberry picking and wildlife and wildflower viewing are significant recreational activities and have been for many years.

We cannot anticipate all future information needs, but all past experience indicates that this type of long-term study data has great value for a variety of purposes, including some not envisioned at the time of establishment. It therefore is important that measurement of this study be continued at regular intervals for at least the next several decades. It can provide an important and unique segment of the information needed.

## Literature Cited

**Barnes, George H.** 1962. Yield of even-aged stands of western hemlock. Tech. Bull. 1273. Washington, DC: U.S. Department of Agriculture, Forest Service. 51 p.

**Boecksteigel, Lee. 1982.** Management experience of Pacific silver fir from the Forest Service Mt. Baker-Snoqualmie view. In: Oliver, Chadwick Dearing; Kenady, Reid M., eds. Proceedings of the biology and management of true fir in the Pacific Northwest symposium; 1981 Feb. 24-26; Seattle, WA. Inst. For. Resour. Contrib. 45. Seattle: University of Washington, College of Forest Resources: 305-310.

**Bonnor, G.M.; De Jong, R.J.; Boudewyn, P.; Flewelling, J.W. 1995.** A guide to the STIM growth model. Inf. Rep. BC-X-353. Victoria, BC: Canadian Forest Service, Pacific Forestry Centre. 38 p.

**Brockway, Dale G.; Topik, Christopher; Hemstrom, Miles A.; Emmingham, William H. 1983.** Plant association and management guide for the Pacific silver fir zone: Gifford Pinchot National Forest. R6-Ecol-130a-1983. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 122 p.

**Deer, Ted. 1982.** True fir management—Cascade silver fir stands. In: Oliver, Chadwick Dearing; Kenady, Reid M., eds. Proceedings of the biology and manage ment of true fir in the Pacific Northwest symposium; 1981 Feb. 24-26; Seattle, WA. Inst. For. Resour. Contrib. 45. Seattle: University of Washington, College of Forest Resources: 311-314.

**Eyre, F.H. 1980.** Forest cover types of the United States and Canada. Washington, DC: Society of American Foresters. 148 p.

**Franklin, Jerry F.; Dryness, C.T. 1973.** Natural vegetation of Oregon and Washington. Gen. Tech. Rep. PNW-8. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 417 p.

**Hann, D.W.; Hester, A.S.; Olsen, C.L. 1997.** ORGANON user's manual: edition 6.0. Corvallis, OR: Department of Forest Resources, Oregon State University. 166 p.

**Harrington, Constance A.; Murray, Marshall D. 1982.** Patterns of height growth in western true firs. In: Oliver, Chadwick Dearing; Kenady, Reid M., eds. Proceedings of the biology and management of true fir in the Pacific Northwest symposium; 1981 Feb. 24-26; Seattle, WA. Inst. For. Resour. Contrib. 45. Seattle: University of Washington, College of Forest Resources: 209-214.

**Harrington, Constance A.; Reukema, Donald L. 1983.** Initial shock and long-term stand development following thinning in a Douglas-fir plantation. Forest Science. 29 (1): 33-46.

**Henderson, Jan A.; Lesher, Robin D.; Peter, David H.; Shaw, David C. 1992.** Field guide to the forested plant associations of the Mt. Baker-Snoqualmie National Forest. Tech. Pap. R6 ECOL TP 028-91. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 196 p.

**Henderson, Jan A.; Peter, David H.; Lesher, Robin D.; Shaw, David C. 1989.** Forested plant associations of the Olympic National Forest. R6 Ecol. Tech. Pap. 001-88. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 502 p.

**Herman, Francis R.; Curtis, Robert O.; DeMars, Donald J. 1978.** Height growth and site index estimates for noble fir in high-elevation forests of the Oregon-Washington Cascades. Res. Pap. PNW-243. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 15 p.

**Hoyer, Gerald E.; Herman, Francis R. 1989.** Height-age and site index curves for Pacific silver fir in the Pacific Northwest. Res. Pap. PNW-RP-418. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 33 p.

**Husted, Lynn; Korelus, Vladimir. 1982.** Management of true fir species for timber production—south coastal British Columbia and the Olympic Peninsula. In: Oliver, Chadwick Dearing; Kenady, Reid M., eds. Proceedings of the biology and manage ment of true fir in the Pacific Northwest symposium; 1981 Feb. 24-26; Seattle, WA. Inst. For. Resour. Contrib. 45. Seattle: University of Washington, College of Forest Resources: 227-284.

**Logan, Sheila E.; Hemstrom, Miles A.; Pavlat, Warren. 1987.** Plant association and management guide–Willamette National Forest. R6-Ecol 257-A-86. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 223 p.

**Meyer, Walter H. 1937.** Yield of even-aged stands of Sitka spruce and western hemlock. Tech. Bull. 544. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 86 p.

**Murray, Marshall D.; Coble, Dean; Curtis, Robert O. 1991.** Height growth of young Pacific silver fir and noble fir established on clearcuts in the Pacific silver fir zone of western Washington. Canadian Journal of Forest Research. 21: 1213-1221.

**Oliver, Chadwick Dearing; Kenady, Reid M., eds. 1982.** Proceedings of the biology and management of true fir in the Pacific Northwest symposium; 1981 Feb. 24-26; Seattle, WA. Inst. For. Resour. Contrib. 45. Seattle: University of Washington, College of Forest Resources. 344 p.

**Pojar, Jim. 1982.** Management of western hemlock-amabilis fir forests for timber pro duction: north coast. In: Oliver, Chadwick Dearing; Kenady, Reid M., eds. Proceedings of the biology and management of true fir in the Pacific Northwest sym posium; 1981 Feb. 24-26; Seattle, WA. Inst. For. Resour. Contrib. 45. Seattle: University of Washington, College of Forest Resources: 253-275.

**Reukema, Donald L. 1975.** Guidelines for precommercial thinning of Douglas-fir. Gen. Tech. Rep. PNW-30. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 10 p.

**Schumacher, Francis X. 1926.** Yield, stand and volume tables for white fir in the California pine region. Bull. 407. Berkeley, CA: California Agricultural Experiment Station. 26 p.

**Schumacher, Francis X. 1928.** Yield, stand and volume tables for red fir in California. Bull. 456. Berkeley, CA: California Agricultural Experiment Station. 29 p.

**Wiley, Kenneth N. 1978a.** Net and gross yields for natural stands of western hemlock in the Pacific Northwest. For. Pap. 19. Centralia, WA: Weyerhaeuser Forestry Research Center, Weyerhaeuser Co. 124 p.

**Wiley, Kenneth N. 1978b.** Site index tables for western hemlock in the Pacific Northwest For. Pap. 17. Centralia, WA: Weyerhaeuser Forestry Research Center, Weyerhaeuser Co. 28 p.

**Wiley, Kenneth N.; Chambers, Charles J. 1981.** Yields of natural western hemlock stands, a supplement to Weyerhaeuser Forestry Paper No. 19. DNR Rep. 43. Olympia, WA: State of Washington, Department of Natural Resources. 79 p.

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