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True Fir Spacing Trials—10-Year Results

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Abstract

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Eighteen precommercial thinning trials were established in true fir-hemlock stands in the Olympic Mountains and the west side of the Cascade Range during the period 1987 through 1994. This paper updates a previous report, with results for the first 10 years after establishment. Results are given for (1) all trees, (2) the largest 80 per acre of any species, and (3) those noble fir (*Abies procera* Rehd.) and Pacific silver fir (*Abies amabilis* Dougl. ex Forbes) included in the largest 80 per acre. Diameter growth of all species increased with increase in spacing. Height growth of Pacific silver fir decreased with increase in spacing. The largest 80 trees per acre of all species showed some increase in diameter and basal area growth with increased spacing, while height growth declined slightly and volume growth was nearly constant. Over time, these installations will provide a unique source of information on early development of managed stands of these species, for which little information is now available.

Keywords: True firs, *Abies procera, Abies amabilis*, precommercial thinning, spacing, noble fir, Pacific silver fir.

Contents

Introduction

In the period 1987–94, 18 precommercial thinning trials were established in true fir-hemlock stands along the west side of the Cascade Range in Washington and Oregon and in the Olympic Mountains. Establishment of the study and growth during the first 5 years of observation were reported by Curtis and others (2000). The present report is essentially an update of that publication. It will begin by repeating much of the background information given in the previous report, to orient the reader. It then presents results for the first 10 years of growth and some additional comparisons not included in the earlier report.

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 Dyrness 1973) but also with two in the *Tsuga mertensiana* zone. The principal 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, as viewscapes and recreational areas, and have in the past been important as timber-producing forests. Large areas of *Abies amabilis* zone forest exist in the Mount Baker-Snoqualmie (MBS), Gifford Pinchot (GP), Olympic (OLY), Mount Hood (MH), and Willamette (WIL) National Forests (table 1). There are large areas in the national parks in the region and limited areas on Washington Department of Natural Resources (WDNR) lands and private ownerships. There are also large areas on

Table 1—Areas of *Abies amabilis* zone forest in five national forests in the study area

National forest	*Abies amabilis* zone	
	Percent	*Acres*
Mount Baker-Snoqualmie	40.2	733,654
Olympic	29.0	190,544
Gifford Pinchot	42.7	587,631
Mount Hood	41.6	457,224
Willamette	38.9	686,856

Source: Henderson, J.A. Potential natural vegetation zones of Washington. Manuscript in preparation.

Vancouver Island and in the Coast Range of British Columbia that are important timber-producing areas.

Previous Research

Little information exists on true fir stand development.

Although there is a considerable body of information on stand development, yields, and site evaluation for low-elevation hemlock, there is very little information available on the true firs and high-elevation true fir-hemlock mixtures.

Herman and others (1978) and Hoyer and Herman (1989) developed height growth and site index estimates for noble fir and Pacific silver fir, based on stem analyses of trees from unmanaged old-growth stands. These are only doubtfully applicable to young stands because of differences in stand establishment, early competition, climatic changes, and possible biases associated with changes in relative 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 may later equal or surpass their associates because of the long period of rapid and uniform height growth.

Oliver and Kenady (1982) provided a summary of existing information as of that date. The various U.S. Forest Service plant association guides have since presented several indicators of productivity by plant association (Brockway and others 1983; Hemstrom and others 1982; Henderson and Peter 1984; Henderson and others 1989, 1992; Logan and others 1987).

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 the slash, and plant—often with Douglas-fir. A high proportion of these early plantations failed, and regeneration to true fir-hemlock took place by natural seeding over an extended number of years. The resulting stands were often patchy and contained considerable variability in tree sizes and ages.

Over subsequent years, better species selection combined 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 fir-silver fir mixtures, with other species such as Engelmann spruce (*Picea engelmanni* Parry ex Engelm) or western white pine used on some frost-prone sites. Reduced use of fire favored survival of natural advance regeneration of Pacific silver fir and western hemlock. Numerous young true fir-hemlock stands now exist at higher elevations along the west side of the Cascade Range and in the Olympic Mountains.

There are considerable areas of young true fir-hemlock stands.

Extensive precommercial thinning began in the late 1970s. There has been some question about the feasibility or desirability of future commercial thinning because many stands are on steep terrain and because 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. Some have further reduced the number of leave-trees, with the expectation that no further stand entry might be feasible until final harvest. This raised concerns about the effects of number of residual trees on future stand development and average tree size at which precommercial thinning (PCT) should be done.

Today much of the land under the Northwest Forest Plan is in late-successional old-growth forest reserves (including wilderness). The rest is mostly in matrix or adaptive management areas. About 40 percent of these areas are in the *Abies amabilis* zone[1]. In some areas the management goal is future timber production, whereas others are managed primarily for watershed, wildlife, or recreation values. Much of the area under the Northwest Forest Plan is currently managed for old growth protection, restoration of old growth or protection of old-growth-dependent species. Whatever the present or possible future management objectives, very little is known about the dynamics of young true fir forests.

The Study

In the period 1987–94, the Pacific Northwest Research Station (PNW) installed a series of 18 spacing trials in true fir-hemlock, with assistance from the Pacific Northwest Region of the U.S. Forest Service and the individual national forests concerned. The trials were established in stands considered ready for PCT under then-current operational practices. Seven were on the MBS, one on the OLY, five on the GP, four on the MH, and one on the WI National Forests.

[1] Henderson, J.A. 2007. Personal communication. Area Ecologist, Mount Baker-Snoqualmie and Olympic National Forests.

Objectives

Quantitative information is needed on response to precommercial thinning.

Study objectives are (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.
It is hoped that these trials will ultimately provide:

- Information on development of precommercially thinned stands needed for reliable estimates of productivity of young true fir-hemlock stands.
- Data useful, in combination with other data, for construction of stand simulators and yield projection systems for young-growth managed stands.
- A basis for choosing the optimum number of leave trees to meet different management goals.
- Information on successional and structural development over time for possible use in meeting landscape diversity, species habitat, and watershed management objectives.

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.

For some years prior to the study, the national forests had been conducting an extensive precommercial thinning program in young true fir-hemlock. Choice of locations was therefore constrained by the fact that many stands otherwise suitable for the study had already been operationally thinned.

Sites selected (fig. 1) ranged from 3,000 to 4,500 ft in elevation. Most of the plant associations found on the study sites have widespread distribution within the respective national forests, according to the various area plant association guides.

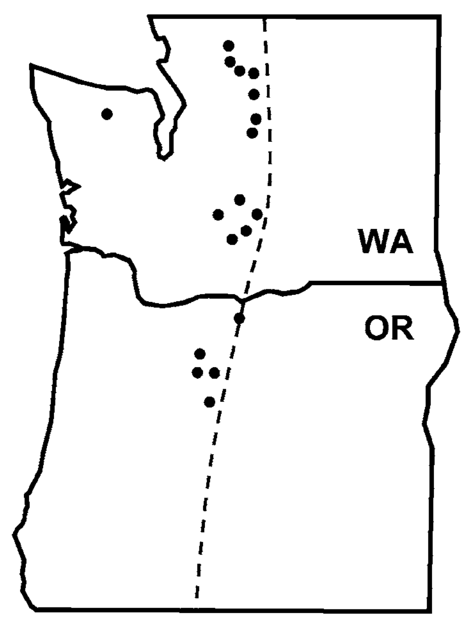

Figure 1—Locations of study areas in western Washington and Oregon.

Study Design

The study uses a randomized block design, with six treatments per block. 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. Of the 18 installations established, 3 have 12 plots and 15 have 6 plots.

Treatments—

The treatments consisted of five spacings, plus no treatment (NT). It was expected that the untreated plot(s) would be useful for demonstration purposes and possibly in analytical comparisons. The spacings and corresponding target values per unit area 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.

Plot design—

Measurement plots were square, within a larger treatment plot (fig. 2), of the dimensions given in table 2. In the first installation, the treatment plot was 200 ft on a side. Thereafter, it was reduced to 180 ft (occasionally 160 ft) because of the difficulty in fitting plots into available area. The plot sizes selected were thought 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.

Measurement plot size was about 0.25 acre, with a slightly smaller plot (0.20 acre) for the unthinned plot and somewhat larger areas for the two widest spacings, so that a reasonable number of leave trees would be included. To facilitate control of leave-tree marking, the sides of the measurement plot were made multiples of the desired spacing, thus allowing subdivision of the plot into strips corresponding to the desired spacing.

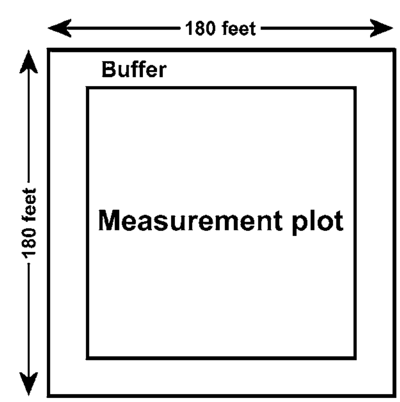

Figure 2—Basic plot design.

Table 2—Standard dimensions of plots used in true fir spacing trials

	Treatment plot			Measurement plot		
Treatment	**Spacing**	**Area**	**Side**	**Area**	**Side**	**Buffer width**
Number/acre [a]	*Feet*	*Acres*	*Feet*	*Acres*	*Feet*	*Feet*
No thin	–	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.

Plot Establishment and Measurement

Plot layout—

True fir-hemlock stands are characteristically patchy and 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. Treatments were assigned randomly after the treatment plots were located 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 ft.

Initial tree measurements and marking—

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. To the extent possible, an effort was made to adjust all treated plots within an installation to nearly comparable species composition. Vigor was given precedence over strict adherence to spacing or species criteria. Occasional exceptionally large trees were excluded to make leave-tree diameter distributions and average diameters more comparable.

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.

All trees 0.6 and larger in diameter at breast height (d.b.h.) were tallied by species and 1-in d.b.h. classes at all measurement plots to be thinned.

Leave-tree measurements—
Trees were measured after the growing season. Diameters at breast height were measured to the nearest 0.1 in (by diameter tape) on all leave trees on thinned plots, and all trees 0.6 in and larger d.b.h. present at establishment on the unthinned plots. Heights and heights to live crown were measured to the nearest 0.1 ft (with height poles or—in later remeasurements—laser instrument). Heights were measured on all leave trees at the two widest spacings, on the first two of every three trees at the 12.8-ft spacing, and on every other tree 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. Trees were selected 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, excluding trees showing a suppressed core. There was considerable variation because of difference 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 were then used to estimate the average number of rings at breast and stump heights corresponding to mean diameter of leave trees on all thinned plots at an installation. Total age was taken as the estimated number of rings at stump + 3 (table 3) 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 and were not included in the above age estimates.

Description of ground vegetation—
All installations were classified by dominant plant association (tables 4 and 5), in most cases, by the area ecologist for the given national forest. Much more detailed descriptions were made for those installations located in the MBS and OLY National Forests (Curtis and others 2000), including ground vegetation species identification and inventory.

Pre- and postthinning conditions—
Estimated total stand ages at establishment ranged from 14 to 41 years. Elevations ranged from a low of 3,000 ft (Bonidu) to 4,500 ft (Alpine #4).

Pretreatment installation values (based on the untreated plots) for trees per acre, basal area, and quadratic mean diameter (QMD) are given in table 6. Initial trees per acre (excluding trees less than 0.6-in d.b.h, some of which became leave trees)

Table 3—Basic descriptive information for the true fir spacing study installations

Installation	National forest[a]	Plots	Year established	Stand origin	Breast-high age[b]	Age at stump	Total age	Elevation	Dominant plant association[c]
		No.	*Year*		- - - - - - - - - - *Years*	- - - - - - - - - -	- - - - - - - - - -	*Feet*	
Alpine #4	MH	6	1990	Mixed	11	16	19	4,500	TSME/VAME/CLUN
Bonidu	OLY	6	1990	Natural	16	21	24	3,000	ABAM/VAAL/CLUN
Cabin #2	GP	6	1994	Planted	7	11	14	3,800	ABAM/BENE
Cat Creek	GP	6	1990	Natural	13	20	23	4,300	ABAM/RHAL
Crevice Cr	MBS	6	1988	Mixed	22	26	29	3,000	ABAM/VAAL/CLUN
Cumberland	MBS	6	1988	Natural	12	17	20	3,200	ABAM/VAAL/CLUN
Dog Creek	MH	6	1991	Planted	13	17	20	3,600	ABAM/RHMA/XETE
Evans Creek	MBS	6	1989	Natural	32	38	41	3,700	ABAM/VAAL/CLUN
Haller Pass	MBS	5	1989	Planted	24	29	32	4,200	ABAM/VAME
Iron Mt	MBS	12	1987	Natural	19	25	28	3,500	ABAM/VAAL/CLUN
Job #2	GP	6	1992	Planted	8	14	17	3,700	ABAM/ACTR/CLUN
Marys Creek	WIL	6	1994	Planted	8	12	15	4,000	ABAM/RHMA/BENE
Memaloose	MH	6	1992	Planted	13	21	24	4,000	ABAM/RHMA/XETE
North Mt #2	MH	6	1993	Mixed	12	17	20	3,200	ABAM/VAAL/COCA
Pointer #3	GP	12	1991	Planted	10	14	17	4,100	TSME/VAME/XETE
Rattrap Pass	MBS	6	1988	Mixed	14	20	23	3,200	ABAM/VAAL/CLUN
Tonga Ridge	MBS	6	1989	Mixed	20	26	29	3,800	ABAM/VAAL/CLUN
Twin #1	GP	12	1994	Planted	10	15	18	3,800	ABAM/VAME/CLUN

[a] National Forests (NF) as follows: GP = Gifford Pinchot, MH = Mount Hood, MBS = Mount Baker-Snoqualmie, OLY = Olympic, WIL = Willamette.
[b] Years since attaining breast height.
[c] Plant associations are given in table 3.

Table 4—Species names, true fir spacing trials

Species		
Common name	Botanical name	Acronym
	Trees	
Pacific silver fir	*Abies amabilis* Dougl. ex Forbes	ABAM
Subalpine fir	*Abies lasiocarpa* (Hook.) Nutt.	ABLA
Noble fir	*Abies procera* Rehd.	ABPR
Alaska cedar	*Chamaecyparis nootkatensis* (D. Don) Spach	CHNO
Engelmann spruce	*Picea engelmanni* Parry ex Engelm	PIEN
Western white pine	*Pinus monticola* Dougl. ex D. Don	PIMO
Douglas-fir	*Pseudotsuga menziesii* (Mirb.) Franco	PSME
Western redcedar	*Thuja plicata* Donn ex D. Don	THPL
Western hemlock	*Tsuga heterophylla* Tsuga heterophylla (Raf.) Sarg.	TSHE
Mountain hemlock	*Tsuga mertensiana* Tsuga mertensiana (Bong.) Carr.	TSME
	Shrubs and herbs	
Vanilla leaf	*Achlys triphylla* (Sm.) DC.	ACTR
Dwarf Oregon grape	*Berberis nervosa* Pursh	BENE
Queencup beadlily	*Clintonia uniflora* (Menzies ex J.A. & J.H. Schultes) Kunth	CLUN
Bunchberry	*Cornus canadensis* L.	COCA
Cascades azalea	*Rhododendron albiflorum* Hook.	RHAL
Rhododendron	*Rhododendron macrophyllum* D.Don ex G.Don	RHMA
Alaska huckleberry	*Vaccinium alaskaense* T.J. Howell	VAAL
Big huckleberry	*Vaccinium menbranaceum* D. Don ex G. Don	VAME
Beargrass	*Xerophyllum tenax* (Pursh) Nutt.	XETE

Table 5—Plant associations in true fir spacing trials

Plant associations[a]	
Pacific silver fir/Alaska huckleberry/queencup beadlily	ABAM/VAAL/CLUN
Pacific silver fir/big huckleberry	ABAM/VAME
Pacific silver fir/big huckleberry/queencup beadlily	ABAM/VAME/CLUN
Pacific silver fir/Cascade azalea	ABAM/RHAL
Pacific silver fir/rhododendron/queencup beadlily	ABAM/RHMA/XETE
Pacific silver fir/vanilla leaf/queencup beadlily	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/queencup beadlily	TSME/VAME/CLUN

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

Table 6—Pretreatment descriptive statistics for the true fir study installations, trees 0.6 in diameter at breast height or greater, all species

Installation	Trees/acre	Basal area	QMD[a]	QMD80[b]	H80[c]
	No.	*Ft² /acre*	- - - - *Inches*	*- - - -*	*Feet*
Alpine #4	1,337	39.4	2.32	4.10	17.5
Bonidu	2,343	100.0	2.80	5.91	30.0
Cabin #2	796	21.7	2.25	3.35	15.8
Cat Creek	1,995	30.0	1.66	3.38	18.6
Crevice Creek	2,390	183.5	3.75	8.88	42.3
Cumberland	2,716	65.0	2.09	3.99	22.3
Dog Creek	1,849	44.2	2.09	4.09	20.8
Evans Creek	2,675	181.4	3.53	8.83	49.1
Haller Pass	742	143.6	5.96	8.49	45.5
Iron Mountain	1,453	47.8	2.46	4.83	25.3
Job #2	783	26.4	2.49	3.71	18.1
Marys Creek	1,134	23.4	1.95	3.39	17.2
Memaloose	1,721	49.0	2.29	4.60	20.2
North Mountain	976	39.3	2.72	4.85	22.8
Pointer #3	543	14.3	2.20	4.31	19.6
Rattrap Pass	1,296	72.2	3.25	5.60	30.0
Tonga Ridge	1,465	137.6	4.15	7.99	37.8
Twin #1	386	9.8	2.16	3.63	17.2

[a] Quadratic mean diameter at breast height.
[b] QMD at year 0 of those trees included in the largest 80 per acre at year 10.
[c] Estimated mean height at year 0 of those trees included in the largest 80 per acre at year 10.

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 ft^2 at Twin #1 to 180 ft^2 at Crevice Creek and Evans Creek. The QMD ranged from 1.66 in at Cat Creek to 5.96 at Haller Pass.

Prethinning and postthinning composition by species, expressed as percentages of total basal area, are shown in table 7. Shifts in overall species composition caused by the thinning treatments were generally minor.

Remeasurement Schedule

All plots were remeasured at 5 and 10 years after establishment. Thereafter, they were placed on a 10-year remeasurement schedule, because of limitations of personnel and funding. Ingrowth trees 1.6 in diameter or greater were tagged and recorded.

Table 7—Mean percentage species composition of thinned plots by installation before thinning and immediately after thinning

	Pretreatment				Posttreatment			
Installation	ABAM[a]	ABPR[b]	TSHE[c]	Other	ABAM	ABPR	TSHE	Other
				Percent				
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	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*

Analyses

All comparisons made here are based on those initially tagged trees that survived to the 10-year remeasurement. Ingrowth, if any, is omitted. Trees that died during the 10-year period of observation are omitted. Mortality over the period was generally slight, and on thinned plots, statistics for survivors at year 10 are not appreciably different from those for all leave trees. "Top height" is here defined as the mean height (H80) of trees included in the 80 largest (by d.b.h.) stems per acre.

Three principal analyses were made, for:

- All surviving trees, all species included.
- All surviving trees of all species that at year 10 were included in the largest 80 (by d.b.h.) stems per acre (i.e., the top height component).
- Possible effects of spacing on growth of those noble fir and Pacific silver fir that were included in the largest 80 trees per acre.

All Trees

For each plot within each treatment, summary values were calculated for:

- Number of survivor trees present at year 10.
- Basal area of these trees at years 0 and 10.
- Quadratic mean diameter of these trees at years 0 and 10.
- Volume of these trees at years 0 and 10.

Volume computations used the equations of Browne (1962). His equation for "coast balsam species" was used for both noble fir and Pacific silver fir.

Mean numbers of survivors present at year 10, by treatments, are shown in table 8.

Analyses for the "all survivors" component given below are in terms of simple graphics showing mean values. Trends are self-evident, without further statistical analyses.

Means of survivor basal areas, QMDs, and volumes by treatment, across all installations, are shown in figures 3 to 5. Means and standard deviations of basal area increments, QMD increments, and volume increments are given in table 9.

Largest 80 Trees per Acre, All Species: Graphical Comparisons

The data show strong effects of spacing on growth in diameter, basal area, and volume when all trees present are considered. But many of these trees will not survive to maturity. Alternative comparisons are made here based on the 80 largest (by diameter) trees per acre. This number is somewhere near the number of trees expected to be present in the overstory as stands mature and is probably a number that can be expected to survive over a long period at the lowest stocking of 100 residual trees per acre, and it provides reasonable samples for computation of plot values.

Table 8—Comparison of target numbers of leave trees with mean numbers at year 10

Nominal spacing	Target	Survivors, year 10
Feet	- - - - - *Number per acre* - - - - - -	
No thinning	–	1,575
7.9	700	598
10.1	430	387
12.8	265	256
16.4	163	158
20.9	100	94

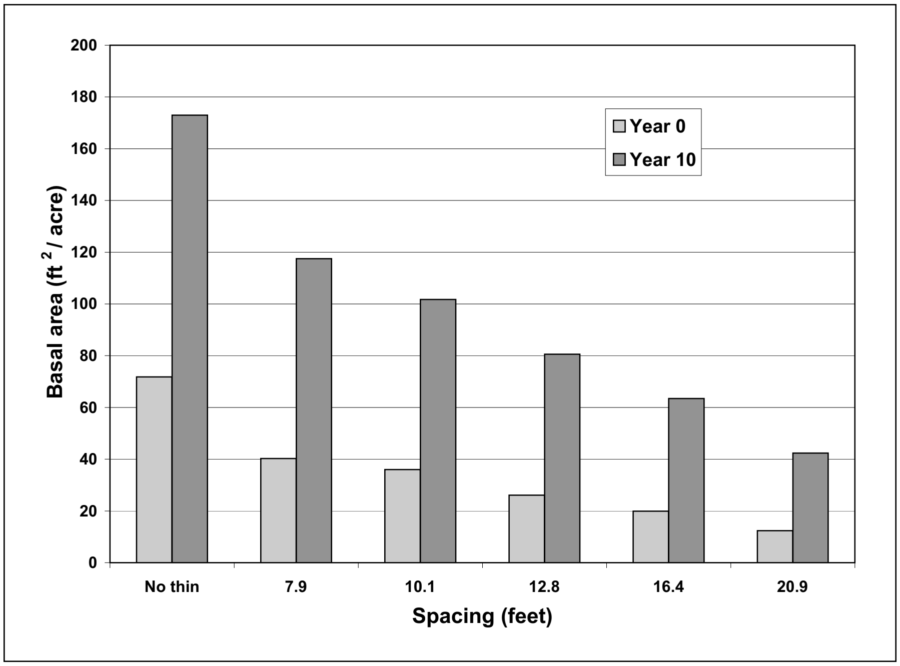

Figure 3—Basal areas of all survivors at years 0 and 10, by treatment.

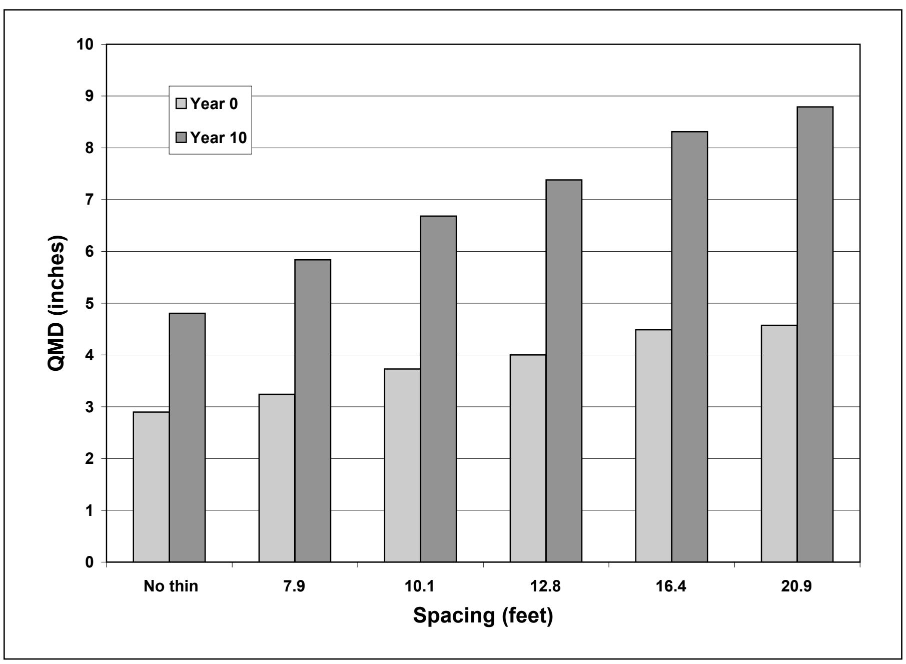

Figure 4—Quadratic mean diameters (QMD) of all survivors at years 0 and 10, by treatment.

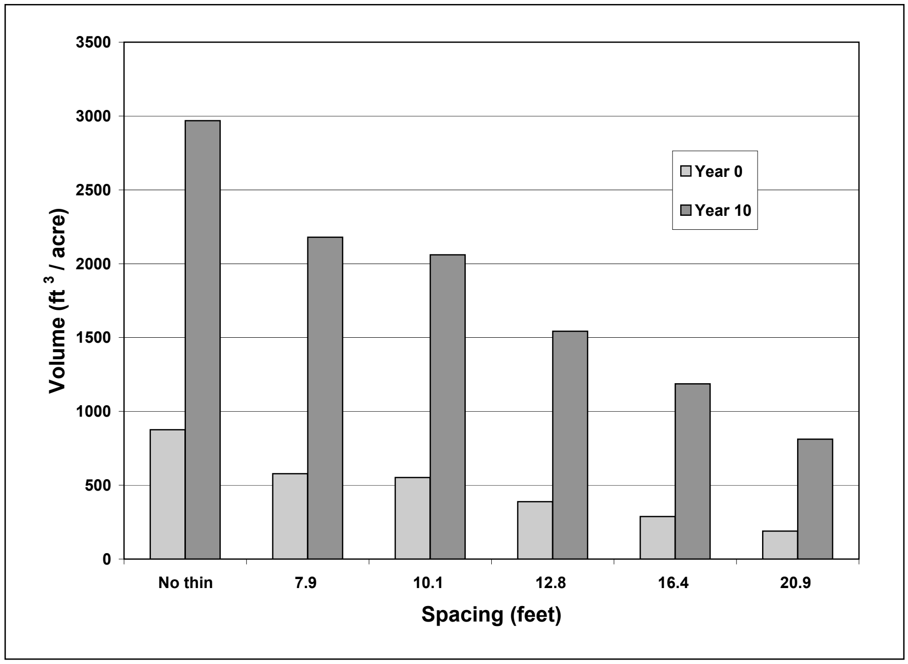

Figure 5—Volumes of all survivors at years 0 and 10, by treatment.

Table 9—Means (and standard deviations) of 10-year increments

Spacing	Basal area	QMD	Volume	Height
Feet	*Ft^2/acre*	*Inches*	*Ft^3 /acre*	*Feet*
All surviving trees				
Not thinned	101.2 (33.5)	1.94 (0.81)	2,093 (1032)	—
7.9	77.3 (28.6)	2.62 (0.68)	1,619 (982)	—
10.1	65.7 (25.7)	2.96 (0.89)	1,508 (1092)	—
12.8	54.4 (20.4)	3.38 (0.86)	1,154 (682)	—
16.4	43.6 (19.0)	3.82 (0.97)	899 (527)	—
20.9	30.0 (13.3)	4.22 (1.20)	622 (381)	—
Largest 80 trees per acre				
Not thinned	21.0 (8.7)	3.28 (0.95)	521 (269)	17.35 (3.79)
7.9	22.1 (9.8)	3.53 (0.95)	548 (342)	16.92 (4.33)
10.1	24.6 (7.5)	3.93 (0.98)	571 (299)	16.05 (3.75)
12.8	24.4 (8.9)	3.95 (0.91)	583 (322)	16.49 (5.02)
16.4	26.5 (9.5)	4.14 (0.93)	526 (309)	15.34 (3.92)
20.9	27.3 (11.6)	4.36 (1.22)	588 (334)	15.47 (4.35)

QMD = quadratic mean diameter at breast height.

Mean 10-year increments in basal areas (B80), QMDs (QMD80), heights (H80), and volumes (V80) for all installations combined are shown in figures 6, 7, 8 and 9 and table 9, for thinned and unthinned treatments. There appear to be considerable increases in basal area increment and diameter increment with increasing spacing (decreasing number of trees), little effect of spacing on volume increment, and a slight decrease in height increment with increasing spacing.

Figures 10, 11, 12, and 13 show individual installation trends in basal area increment, QMD increment, height increment, and volume increment in relation to

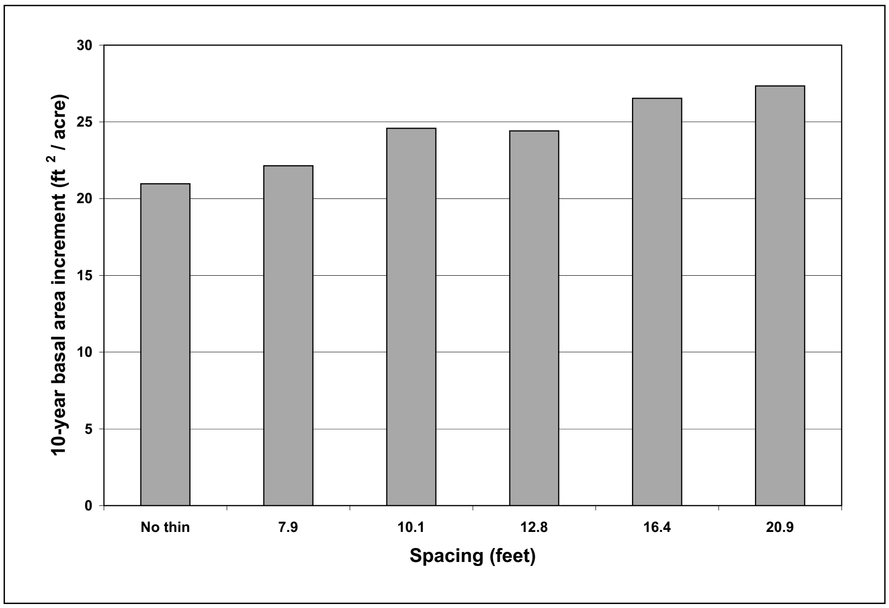

Figure 6—10-year basal area increment of largest 80 trees per acre, years 0 to 10, by treatment.

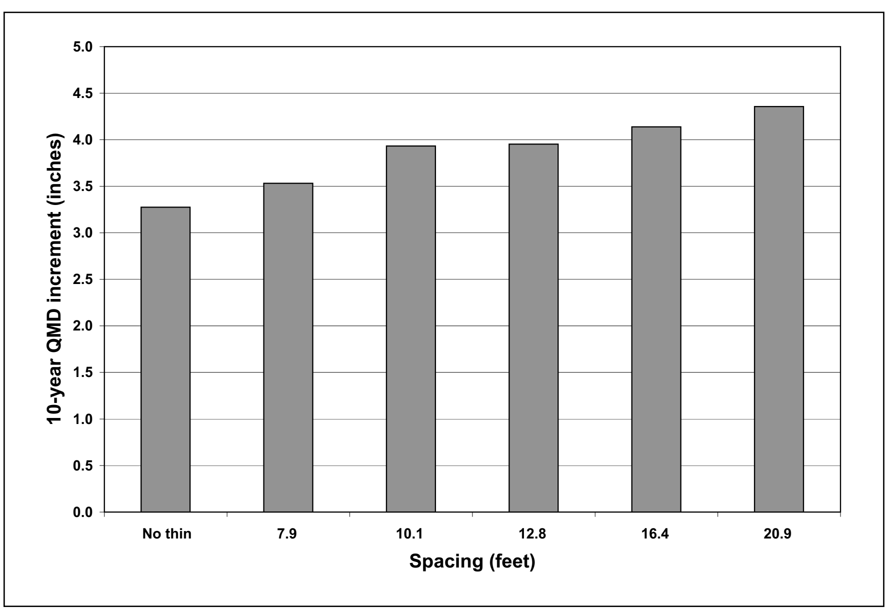

Figure 7—10-year quadratic mean diameter (QMD) increment of largest 80 trees per acre, years 0 to 10, by treatment.

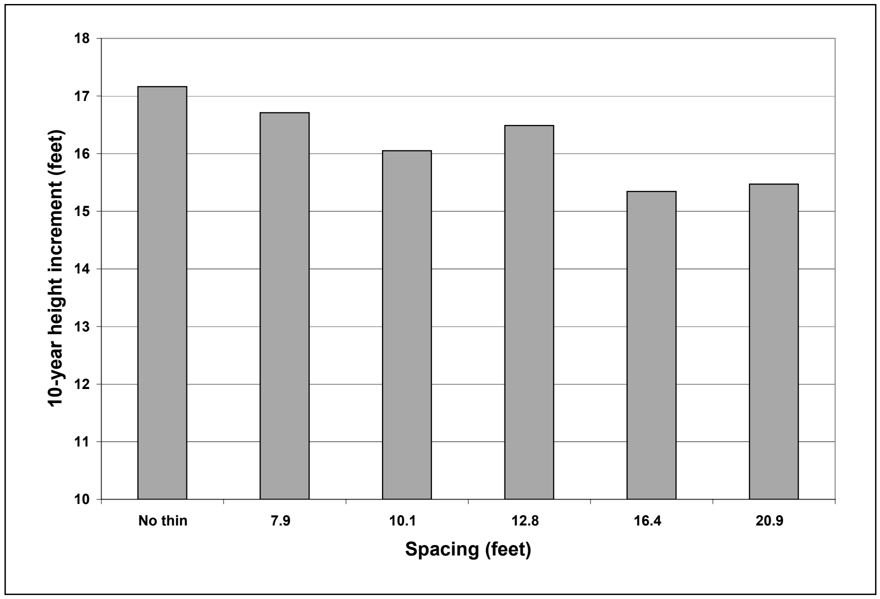

Figure 8—10-year height increment of largest 80 trees per acre, years 0 to 10, by treatment.

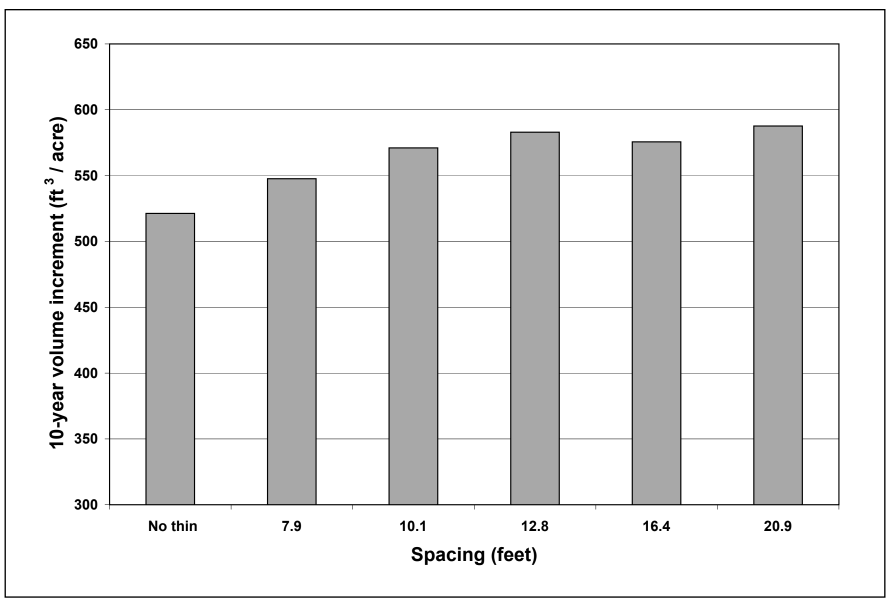

Figure 9—10-year volume increment of largest 80 trees per acre, years 0 to 10, by treatment.

the overall trends represented by the heavy line, for thinned treatments only. There are large differences in curve elevations among installations, and in some installations there are also considerable irregularities in trend with spacing. Overall, the plots suggest that the individual installation trends could be regarded as straight lines more or less parallel to the overall mean but different in elevation.

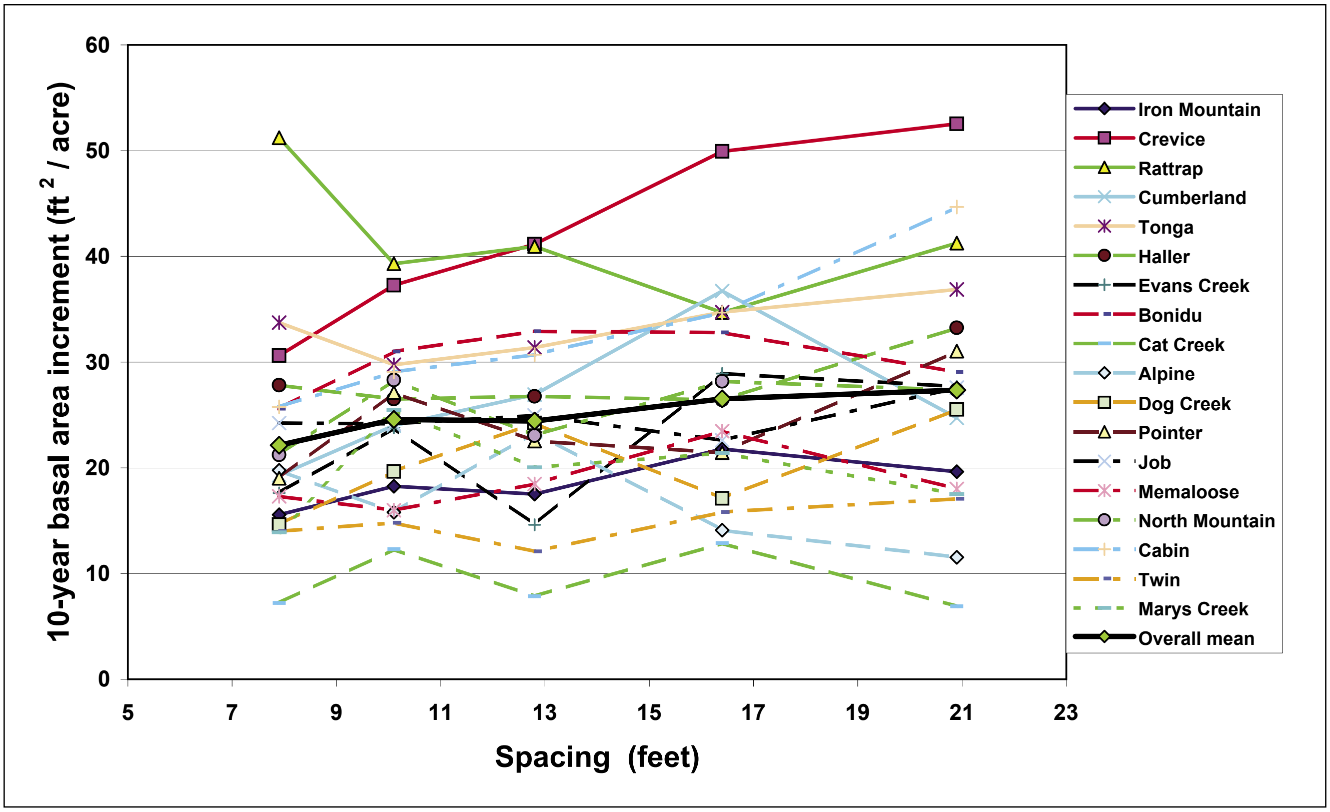

Figure 10—10-year basal area increment of largest 80 trees per acre, years 0 to 10, by installation.

Increment of Largest 80 Trees per Acre, All Species: Statistical Comparisons

Spacing affects development of dominant trees.

Basal area increment (ΔB80) of largest 80 trees per acre, all species— Individual installation curves of ΔB80 over spacing differ widely in curve elevation (fig. 10). Slopes also differ somewhat among installations. Although much variation is present, in general ΔB80 increased with spacing (table 9).

An overall regression not including the effect of blocking provided the equation:

$$\Delta B80 = 19.83 + 0.3831(\text{spacing}) \qquad (1)$$

with $R^2 = 0.035$. This closely approximates the heavy line in figure 10.

Statistical significance of an average slope, specifically the hypothesis that a linear trend over spacing differs from zero, was then tested using orthogonal contrasts for linear trend across the levels of the spacing factor and accounting for installations as a blocking factor, using the GLM (general linear models) procedure of SAS (SAS Institute 1999). The test showed a significant linear trend across the levels of spacing ($p < 0.01$). Installation and spacing together accounted for 0.85 of the total sum of squares.

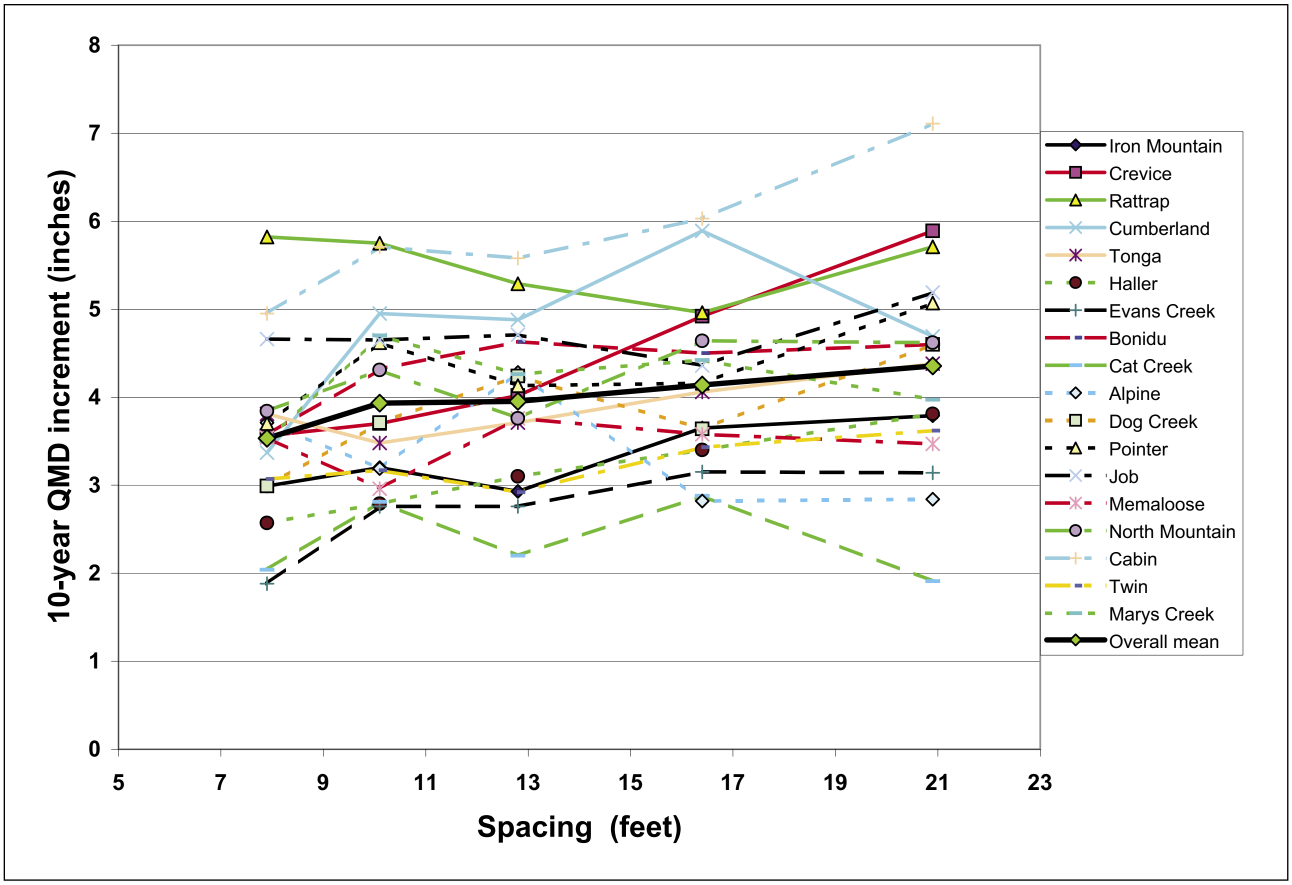

Figure 11—10-year increment in quadratic mean diameter (QMD) of largest 80 trees per acre, years 0 to 10, by installation.

There is a real effect of spacing across installations.

Quadratic mean diameter increment of largest 80 (ΔQMD80) trees per acre, all species—
Figure 11 and table 9 indicate that on average, diameter increment increased with spacing, as would be expected. Again, there is a great deal of variation among installations.

An overall regression not including the effect of blocking provided the equation:

$$\Delta \text{ QMD80} = 3.28 + 0.05249(\text{spacing}) \quad (2)$$

with $R^2 = 0.06$.

This closely approximates the heavy line connecting spacing means in figure 11.

A similar analysis to that used for basal area increment, including installation as a blocking factor, showed a significant linear trend with spacing ($p < 0.01$). Installation and spacing together accounted for 0.83 of the total sum of squares.

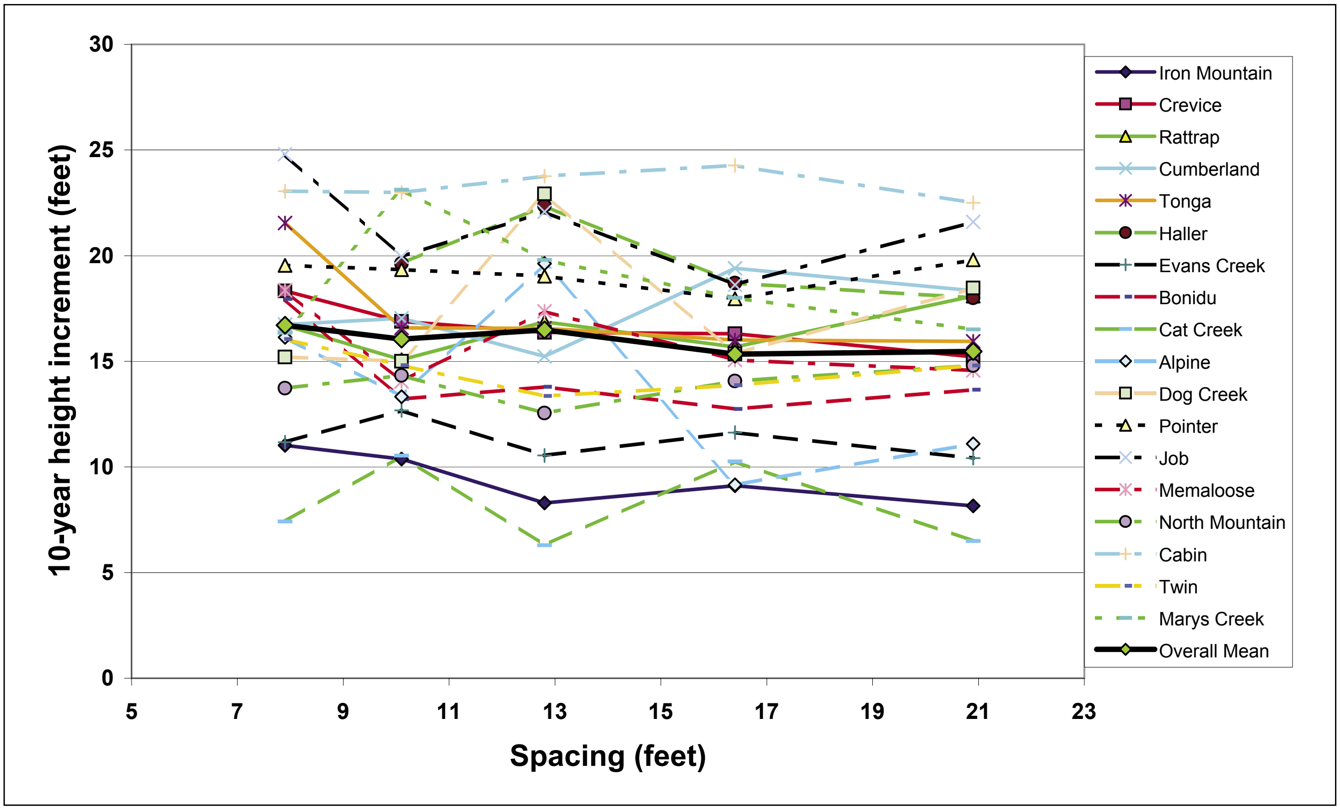

Figure 12—10-year height increment of largest 80 trees per acre, years 0 to 10, by installation.

Top height increment (ΔH80) of largest 80 trees per acre, all species—
Overall means (fig. 8, 12, table 9) suggest a slight decline in ΔH80 with increasing spacing.

An overall regression not including the effect of blocking provided the equation:

$$\Delta H80 = 17.32 - 0.09644(\text{spacing}) \quad (3)$$

with $R^2 = 0.01$.

An analysis similar to the preceding ones, including installation as a blocking factor, showed a significant trend of height increment with spacing ($p = 0.046$). Installation and spacing together accounted for 0.80 of the total sum of squares.

Thus, 10-year height increment of the largest 80 trees decreased with increase in spacing, although this effect was not large (fig. 12).

Volume increment (ΔV80) of largest 80 per acre, all species—
Figure 9 suggests that there is little if any overall relationship of 10-year ΔV80 to initial spacing in thinned plots. As with other variables, there is a great deal of variation among and within installations (fig. 13).

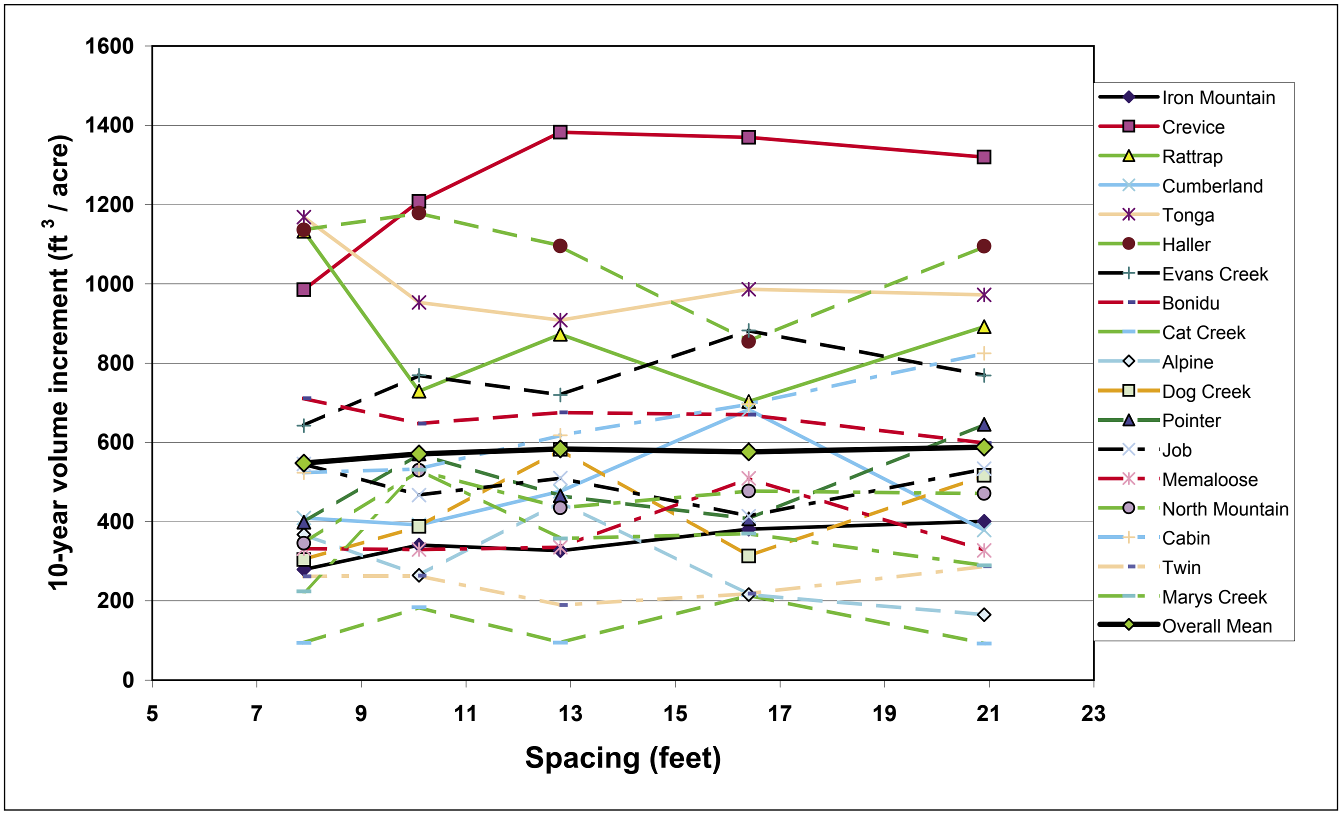

Figure 13—10-year volume increment of largest 80 trees per acre, years 0 to 10, by installation.

An analysis similar to that for basal area and for diameter increment, including installation as a blocking factor, showed no significant effect of spacing on volume increment. Although 0.90 of the sum of squares was accounted for, this was almost entirely due to installation.

The overall mean, $\Delta V80 = 572$ ft^3/ac, closely approximates the spacing means as shown by the heavy line in figure 13.

Comparisons by Individual Species

The above comparisons take no account of differences in species composition among installations and among plots within installations. It seemed of interest to compare growth by species, where the data allow. The dependent variables used here are means of those trees of the given species that are included in the largest 80 per acre.

Noble fir—

Data used were from those installations having noble fir present in the largest 80 component on at least 4 of the 5 thinned plots.

Figure 14 shows the relation of unweighted means of noble fir 10-year height increment to spacing, for the nine installations meeting the above criteria. The overall means seem to show a slight decline with increasing spacing although there is a great deal of variation present. Differences in curve elevation are presumably due mainly to site differences, which we cannot express numerically until stands develop further. Much variation also arises from the fact that the sample available on each treatment within an installation can range from 1 tree to a possible maximum of 29 trees in the widest spacing.

Because the number of available trees of the species differs widely among plots, weights equal to the square root of the number of trees were used in calculating an overall regression, not including blocking as a factor. This weighted regression was:

$$\Delta H80 = 20.3578 - 0.12092 \text{ (spacing)}, \qquad (4)$$

with $R^2 = 0.03$.

An analysis similar to that for the largest 80 of all species, including installation as a blocking factor, showed a marginally significant linear trend with spacing ($p = 0.055$). Installation and spacing together accounted for 0.73 of the total sum of squares.

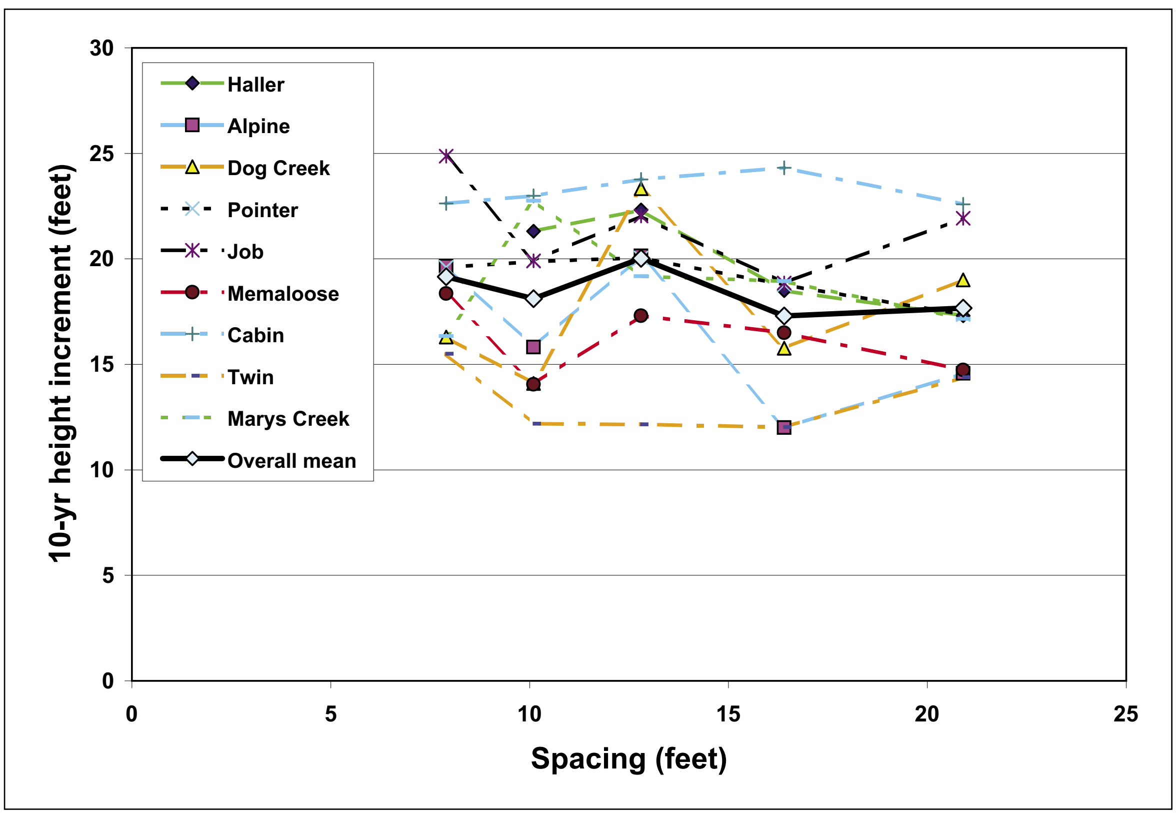

Figure 14—10-year height increment of noble fir included in the largest 80 trees per acre present at year 10, by installation and treatment.

Thus, although the data suggest that there may still be some reduction in height increment with increase in spacing, this is relatively small and much less than at the 5-year analysis (Curtis and others 2000).

Figure 15 shows diameter increment by installation and treatment. An analysis similar to that for height increment showed that average slope was positive and significantly different from zero ($p < 0.01$).

Pacific silver fir—

Figure 16 shows trends of $\Delta H80$ over spacing, for those installations having silver fir present in at least four of the five treatments. The heavy line represents overall means and suggests that height increment decreases with increasing spacing, although there is considerable variation in trends among installations and among spacings within installations.

An overall weighted regression of height increment on spacing, not including the block effect, gave:

$$\Delta H80 = 15.1715 - 0.2322(\text{spacing}), \quad (5)$$

with $R^2 = 0.10$.

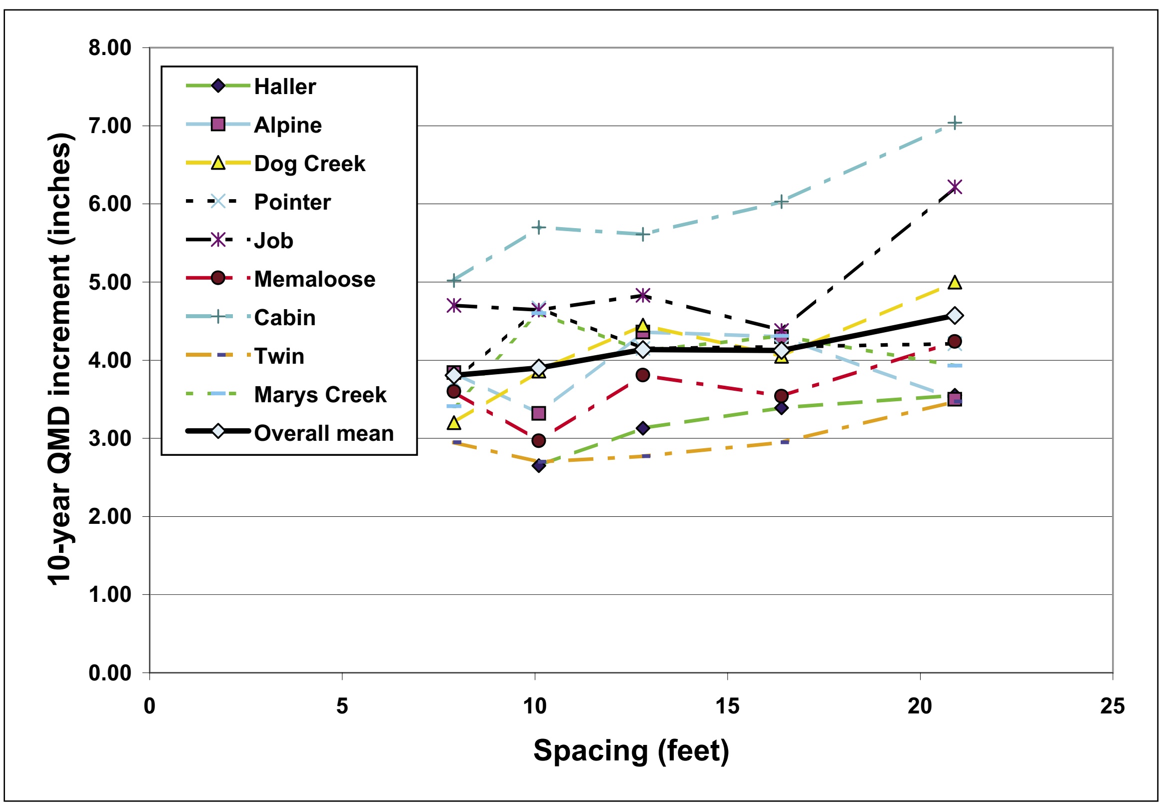

Figure 15—10-year diameter increment of noble fir included in the largest 80 trees per acre present at year 10, by installation and treatment.

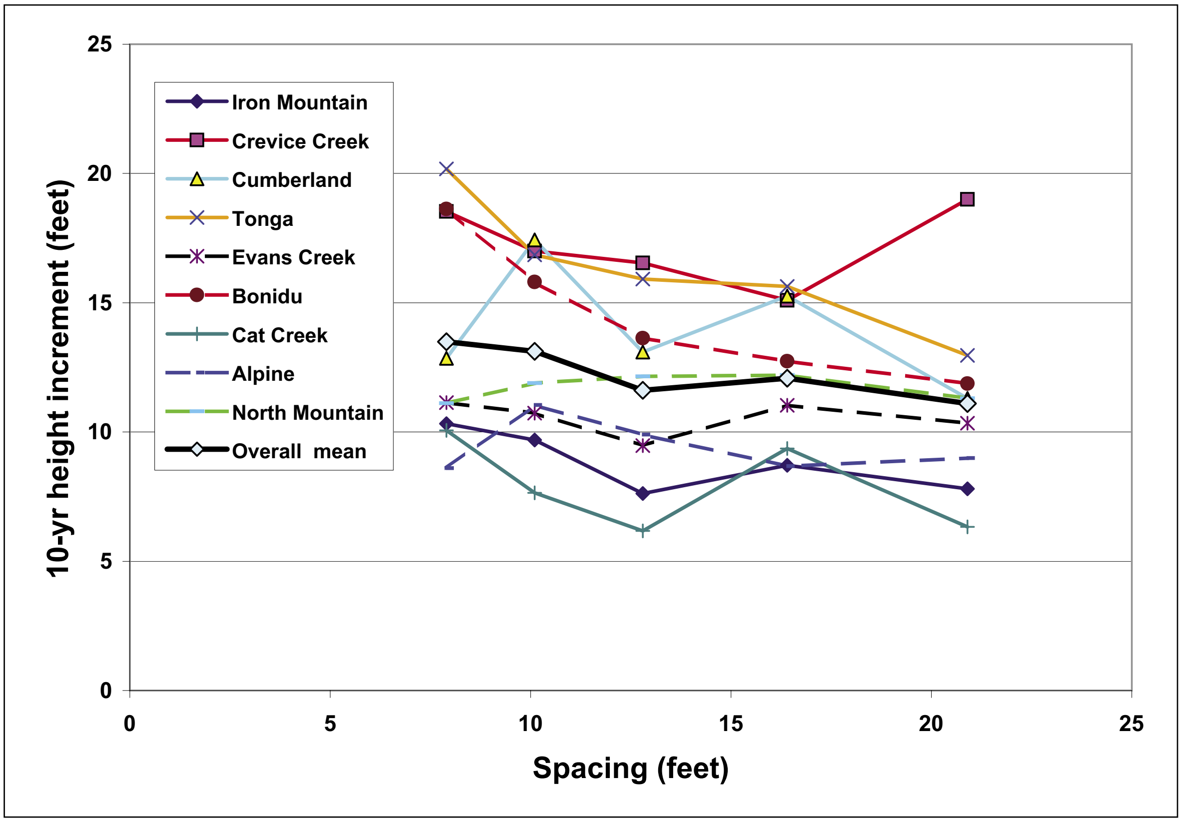

Figure 16—10-year height increment of Pacific silver fir included in the largest 80 trees per acre present at year 10, by installation and treatment.

Wide spacing reduced silver fir height growth.

An analysis similar to that for the largest 80 trees of all species, including installation as a blocking factor, showed a significant linear effect of spacing on height increment ($p < 0.01$). Installation and spacing together accounted for 0.86 of the total sum of squares.

Clearly, height increment has been less at the wider spacings, and the effect is greater than is the case with noble fir.

Figure 17 shows trends of diameter increment with spacing, by installation. An analysis similar to that for height increment showed that average slope was positive and significantly different from zero ($p < 0.01$).

Western hemlock—

Only five installations had sufficient hemlock present in the largest 80 trees per acre across spacings to allow any comparisons. The small amount of data does not allow any clear conclusions, but there is no indication of any relation between height increment and spacing. The data do indicate that diameter increment of hemlock included in the 80 largest trees per acre increased with spacing.

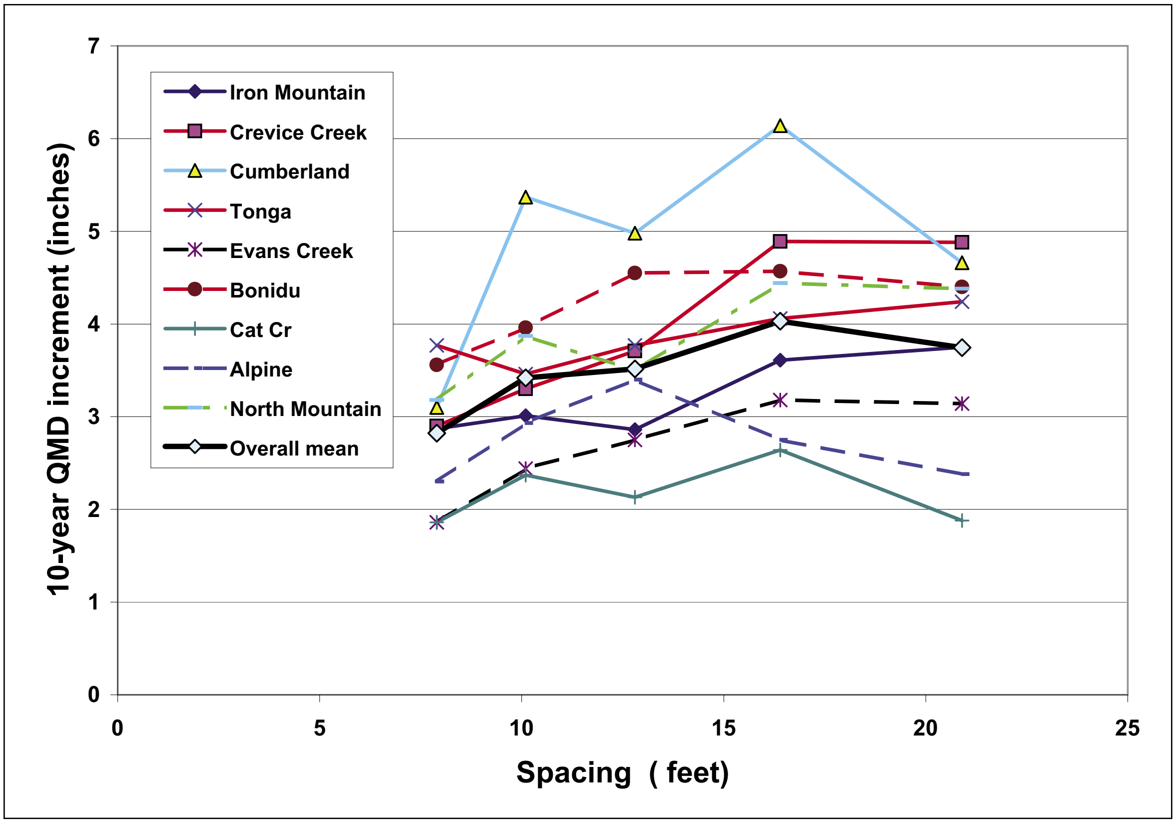

Figure 17—10-year diameter increment of Pacific silver fir included in the largest 80 trees per acre present at year 10, by installation and treatment.

Noble fir height growth exceeds associated species.

Comparative growth by species—

Average 10-year height growth of trees included in the largest 80 per acre, by species, was calculated as arithmetic means of the plot values for those plots included in the previous comparisons. These values were:

	ΔH80	Standard deviation	Range
		Feet	
Noble fir	18.7	3.55	11.4-24.9
Pacific silver fir	12.3	3.61	6.2-20.2
Western hemlock	16.8	1.67	14.0-20.2

A high proportion of the noble fir was of plantation origin, whereas many silver fir and all of the hemlock were from natural seeding. These differences in origin may accentuate the growth differences, but it is clear that growth of dominant noble fir has been superior to growth of comparable silver fir.

Top Height (H80) in Relation to Breast-High Age, All Species Combined

Figure 18 shows the values of H80 at years 0 and 10 after establishment, in relation to breast-high age (years since attaining 4.5 feet height). It is evident that there are wide differences in curve elevation and slope, which presumably are largely an expression of site differences although possibly somewhat modified by differences in species composition.

Discussion

Installation (Block) Effects and Spacing Effects

Comparison of individual installation trends in basal area increment, QMD increment, and volume increment of thinned plots with overall means shows wide differences (figs. 10 through 13) in position of individual installation curves relative to the mean curve, and considerable differences among treatments (spacings) within installations. Differences among installations are far greater than differences

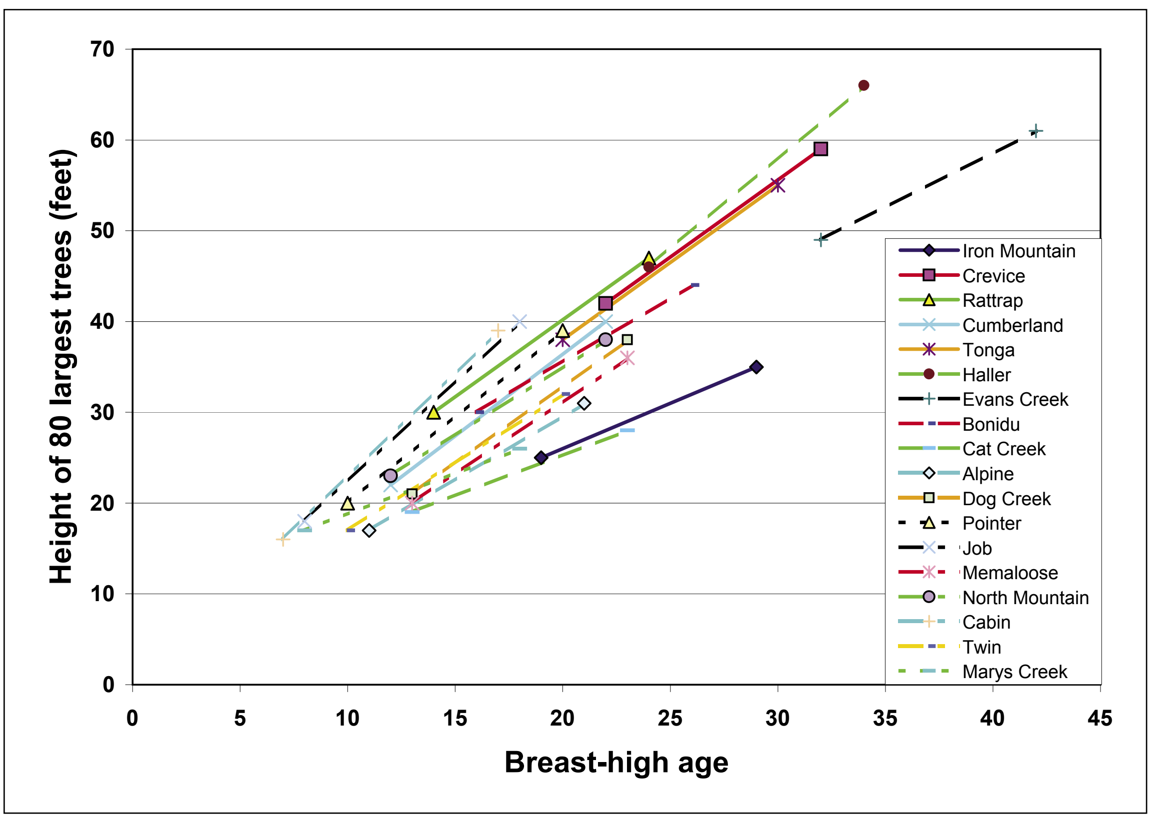

Figure 18—Mean height of 80 largest trees per acre (H80) of all species in relation to age at breast height (age since reaching breast height).

among spacings. This is true for both all trees and for the largest 80. Installation differences arise from several causes:

- Inherent differences in environment and in site productivity.
- Differences in species composition.
- Differences in stage of stand development (height, basal area, QMD, age) at which installations were established.

Although inherent site differences are probably the largest component of these differences, differences in stage of development at plot establishment may also be a factor. The true firs typically have slow early development followed by a period of accelerating growth. Some installations were established during the early phase of slow height growth, whereas others were well into the phase of accelerated growth.

An additional though probably minor factor that may contribute to deviations from the overall trend within an installation is that, although treatments are defined in terms of number of residual trees, and for plotting purposes the corresponding spacing is here treated as equivalent, the actual number of trees is not identical with the target number. Generally, it is somewhat less although not very different (table 8). The principal cause, aside from minor errors in plot establishment and occasional mortality, is the existence of empty cells in the grid used to select leave trees in these often somewhat patchy stands. The differences are thus greater at narrow spacing than at wider spacing.

Now, to summarize the results of analyses to date:

All Survivors

Trends for all survivors are generally similar in kind to those found in early results from many similar experiments with other species. Namely:

- Basal area increment declines with increasing spacing.
- Diameter increment increases with increasing spacing.
- Volume increment decreases with increasing spacing.

The marked increase in QMD (fig. 4) with increasingly wider spacing is in part the result of the removal of generally smaller trees in thinning—the so-called “chainsaw-effect.”

The lower basal area and volume increments at wider spacing simply reflect the fact that at 10 years after treatment, the wider spacings are still quite open and do not fully occupy the site. Presumably this will change over time. Much of the basal area and volume growth at close spacing is on trees that will not survive to maturity. Therefore, the above trends may not be very meaningful for long-term management.

Largest 80 Trees Per Acre

Trees included in the largest 80 per acre at this stage are mostly dominants, and most can be expected to survive for many years. Trends shown by this stand component are therefore much more meaningful in stand management.

For this more restricted stand component, spacing still had considerable effects on growth, although these were of much smaller magnitude than those for all trees and were not always in the same direction. Namely:

- Basal area increment **increased** somewhat with increase in spacing.
- Diameter increment increased with spacing.
- Height increment declined with increase in spacing.
- Volume increment had little relation to spacing at this point.

These relationships are illustrated in figure 19, which expresses values relative to values of the variable in question for the 7.9-ft spacing.

At 10 years after thinning, these stands are still relatively open. As they develop and competition intensifies, it can be expected that effects of spacing on diameter, basal area, and volume growth will increase.

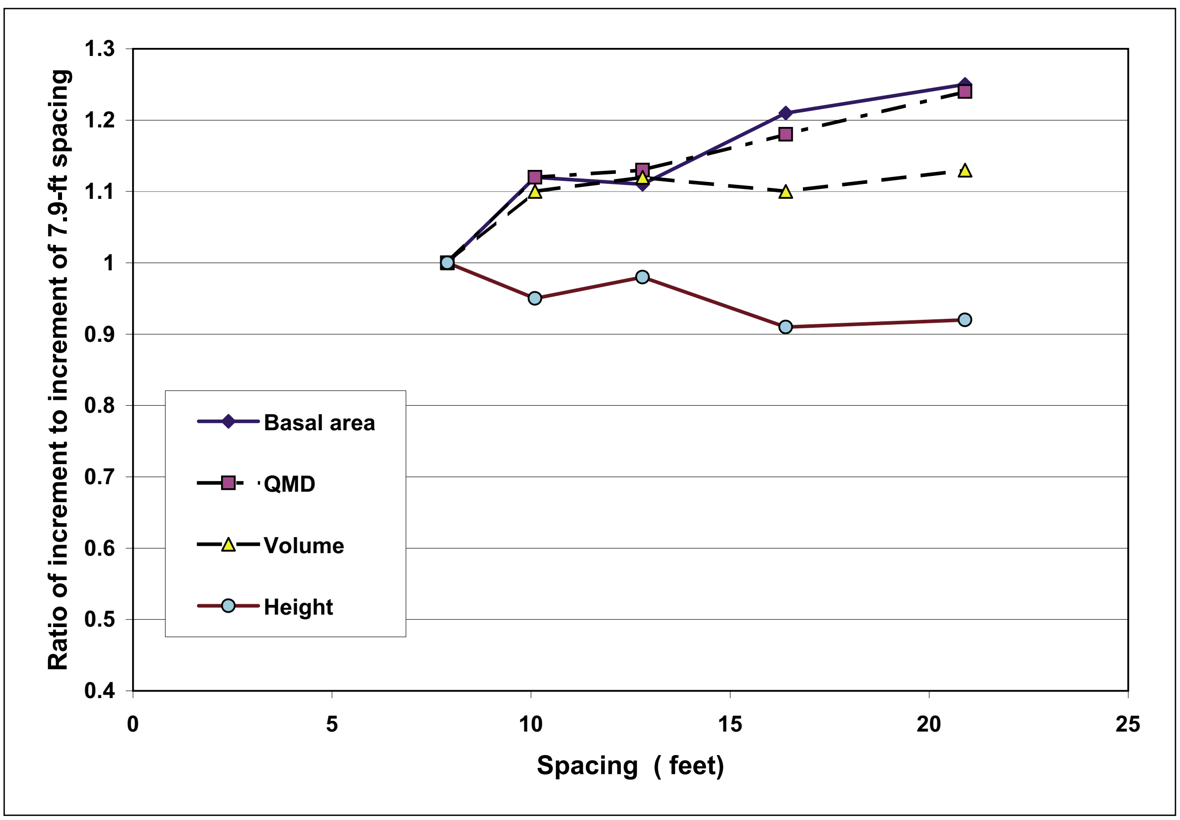

Figure 19—Basal area, quadratic mean diameter (QMD), volume, and height of the largest 80 trees per acre expressed as ratios to the corresponding value for the 7.9-ft spacing.

Reduction in height increment after thinning in other species has sometimes been referred to as "thinning shock." The term seems inappropriate in the present case, because the trees have been growing vigorously. The effect of reduced height increment on volume increment has apparently been offset by increased basal area increment.

Individual Species Comparisons: Trees Included in the Largest 80

The samples available for individual species comparisons are much smaller, both in number of installations with trees of the species present in all or most treatments, and in number of sample trees available by treatment and installation.

Noble fir—

Data suggest a small decline in height increment with increase in spacing, although the effect is much less than that found at the 5-year measurement (Curtis and others 2000).

Trends of diameter growth in relation to spacing are fairly consistent and indicate a moderate increase in diameter growth with increase in spacing.

Pacific silver fir—

Data show a statistically significant decline in height increment with increased spacing. This was also present at the 5-year measurement. (A similar decline was noted in Husted and Korelus 1982).

There is also a fairly strong trend of increasing diameter growth with increasing spacing.

Western hemlock—

With only five installations available for comparisons, little can be said beyond the apparent facts that (1) there is no indication of a trend of height increment in relation to spacing, and (2) there is a clear increase in diameter increment with spacing.

Future Analyses

Periodic increment in basal area (and QMD and volume) should be a function of some combination of (1) spacing; (2) initial postthinning condition, perhaps expressible by top height, basal area, or age; and (3) top height increment. Regressions involving these variables do indeed account for a substantial part of the variation. But, they are not readily interpretable because of the interrelationships among these variables. Purely empirical predictive equations for the first 10 years of growth do not seem useful.

Site quality—

It is obvious from the various graphs presented that there is a great amount of variability in the data. Differences among installations are far greater than those among spacings within installations and represent differences in site productivity and age, possibly somewhat modified by differences in species composition.

Installations differ widely in productivity.

Site productivity differences would be best represented by comparative heights at a specified reference age, interpretable as site index values. At present there is no satisfactory basis for calculating these. It is clear (fig. 18) that there are wide differences in height development among installations. Although site curves exist, the curves now available (Herman and others 1978, Hoyer and Herman 1989) were derived from stem analyses of old trees whose conditions of origin and early development may have been considerably different from those of the present. They may not be a satisfactory representation of development of these young stands.

When 20-year data become available (2014 as now scheduled), heights at a common breast-high age of 25 years will be available for all installations, via reasonable interpolation or extrapolation. These could be used as site indices in analyses and should account for a large part of the differences among installations. They should provide quantitative values useful as predictors of growth and directly interpretable by plant association, and possibly in relation to other environmental variables. It will also then be possible to compare actual observed development of these young stands with that predicted by the existing site curves and to determine applicability of the existing curves to young stands. With four points available for growth curves, it should be possible to compare observed growth rates in basal area, QMD, height, and volume at this common age with site index, initial spacing, and alternative measures of stocking.

Stand structure and understory development—

Curtis and others (2000) gave some limited information on differences in understory vegetation composition and development at several of the older installations. There has been some further data collection by Henderson on the MBS and OLY Forests, but as yet no subsequent published analysis.[2] Further measurements of ground vegetation and associated species may also lead to better understanding of the effect of environmental factors (geology, soils, precipitation, and temperature regimes) beyond simple site index estimates. Data are being collected on development of tree species ingrowth, although with only 10 years of record, there has been no analysis of this aspect as yet.

[2] Source: Henderson, J.A. Potential natural vegetation zones of Washington. Manuscript in preparation.

A very important aspect of the study is the information it can provide on successional trends and the effects of early stocking control on later stand development and stand structure. Early stocking control clearly accelerates the development of large trees, and different residual numbers of trees have a strong influence on the amount of ingrowth and its rate of development, and on composition and vigor of understory vegetation. Ingrowth at the wider spacings has been abundant, and will likely eventually produce layered stands with structures differing considerably from those developing at close spacings. These differences are likely to be important for wildlife, recreation, and timber production objectives. No quantitative comparisons have been made here because of the short (10-year) period of record, but development of ingrowth should be addressed when the 20-year measurements become available.

Spacing affects understory development.

As might be expected, the differences in residual stand density have strong effects on composition and vigor of understory vegetation. There are also strong effects on huckleberry (*Vaccinium spp.*) production (important to recreationists and local native American communities). Differences in understory composition and stand structure will need evaluation from the standpoints of wildlife biology, biodiversity, and old-growth restoration.

Some of these differences are illustrated by the Iron Mountain installation, which is the only one for which we have 20-year measurements at this time. The unthinned plots are extremely dense, with little understory remaining (fig. 20). The intermediate spacing is approaching full canopy cover while retaining understory vegetation (fig. 21). The very wide spacings are still quite open and have a dense shrub understory (fig. 22) and a developing younger cohort of conifers (fig. 23).

These subjects should be addressed for the overall series at some time in the future. It will require a major effort in addition to the normal stand remeasurements, and will need active participation by a plant ecologist. At this time, personnel and funding limitations prevent addressing these questions, but they should have high priority if and when resources become available.

Up to this point, mortality has been minor and has not been considered in these analyses. Mortality will probably not remain minor in the future, and will also need attention in the 20-year analysis.

Future of the Study

Although the number of installations is only about half that originally planned, the study still constitutes a unique source of information on growth patterns and development of true fir-hemlock stands over a range of densities. Its value will increase rapidly with advancing age. The data should be extremely valuable as a

Figure 20—Unthinned plot at Iron Mountain at the 20-year remeasurement.

Figure 21—
10.1-ft spacing at Iron Mountain at the 20-year remeasurement.

Figure 22—Wide spacing (16.4 ft) at Iron Mountain at the 20-year remeasurement has developed large trees and a dense shrub understory (mostly *Vaccinium alaskaense*).

part of that needed to construct reliable growth models for these species that will be applicable to a range of management regimes and objectives.

There are a million acres or more of young (<70 years) Pacific silver fir zone forests in Oregon and Washington (see footnote 1). Under current management direction, many of these forests are being managed as old-growth reserves, yet there is almost no information about successional development of these forests or about how they could be managed to restore old-growth conditions, if desired.

Figure 23—20.9-ft spacing at Iron Mountain at the 20-year remeasurement, showing shrub understory and developing younger cohort of conifers.

There is very little research about how to restore targeted biodiversity to this landscape, about how these young stands might differ from their predecessors, or how they may develop under possible future climatic change. Future measurements of projects such as this one are needed to meet the substantial information gap for management of these forests.

These installations provide a unique information source.

At present, we lack quantitative and site-specific information on growth rates, patterns of development, potential yields, and effects of active management. This is—to our knowledge—the only study of the kind in existence. Without long-term growth data such as this study can provide, there is little basis for evaluating the productive potential of such stands under management or for construction of management guides or growth models applicable to any kind of active management. Additionally, these installations provide an opportunity to assess the effects of a wide range of tree densities on composition and growth of understory vegetation; which are important in these upper elevation forests, where berry picking, hunting, and wildlife and wildflower viewing are significant recreational activities.

The present publication is a progress report detailing the present status of the study and a few preliminary comparisons. A much more thorough analysis will only become possible with completion of the 20-year remeasurements, expected in 2014. It is therefore important that these remeasurements be carried out as scheduled.

There are major obstacles at present. Aside from immediate limitations in personnel and funding, the recent deemphasis of timber production as an objective on the national forests means a loss of the strong support that originally made the study possible. Another obstacle, potentially serious, is that the current program of road closures may make some installations inaccessible. Yet, all history indicates that policies and needs will change over time. Although some people tend to dismiss the importance of these high-elevation forests for timber production, these forests include a wide range of potential productivity and some stands are highly productive. There is no substitute for reliable information on development patterns and silvicultural responses as a basis for future decisions on management options.

We cannot anticipate all future information needs, but all past experience indicates that long-term studies such as this have great value for a variety of purposes, including some not envisioned at the time of establishment. It is therefore important that measurement of this study be continued at regular intervals for the next several decades.

Acknowledgments

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Metric Equivalents

When you have:	Multiply by:	To find:
Inches (in)	2.54	Centimeters
Feet (ft)	0.3048	Meters
Miles (mi)	1.609	Kilometers
Square feet (ft^2)	0.929	Square meters
Acres (ac)	0.405	Hectares
Trees per acre	2.471	Trees per hectare
Square feet per acre (ft^2/ac)	0.229	Square meters per hectare
Cubic feet per acre (ft^3/ac)	0.07	Cubic meters per hectare

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