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Stand Characteristics of 65-Year-Old Planted and Naturally Regenerated Stands Near Sequim, Washington

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Abstract

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Tree numbers, height, and volume were determined in six 63- to 66-year-old plantations of coast Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco var. *menziesii*) in northwest Washington. These stands resulted from the first extensive plantings of this species in the Pacific Northwest. Data from 0.25-acre plots in these plantations were compared to those from matched plots in adjacent, naturally regenerated stands with the same history of logging, wildfire, and absence of further silviculture after regeneration. Planting resulted in well-stocked Douglas-fir stands with volunteers of other tree species. Natural seeding resulted in similarly stocked stands of western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) with Douglas-fir in the dominant crown class. Average live volume was similar in both stand types; only the proportion by species differed. Mean annual rate of volume growth since planting averaged 208 cubic feet per acre, which averaged 2 percent more than in adjacent natural stands.

Keywords: Douglas-fir, western hemlock, western redcedar, planting, natural regeneration, yields, site index.

Summary

We installed six matched pairs of plots in several 63- to 66-year-old stands in a single watershed to compare stand characteristics in plantations of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco var. *menziesii*) with adjacent naturally regenerated stands. Planting after clearcutting and wildfire in the Snow Creek drainage in western Washington resulted in Douglas-fir type instead of western hemlock (*Tsuga heterophylla* (Raf.) Sarg.). Total number of live stems was similar for both methods of regeneration; however, planted stands averaged 184 more live stems per acre of Douglas-fir but 213 fewer stems of western hemlock than naturally regenerated stands. Planted stands averaged a larger proportion and greater number of trees in the 11- through 20-inch d.b.h. (diameter at breast height) size classes. Despite an average 2.8-year delay in planting after wildfire, dominant Douglas-fir in planted stands averaged 4 fewer years to attain breast height than did naturally regenerated Douglas-fir. Planting did not, however, result in greater total volume production (mean for planted = 13,162 cubic feet per acre vs. 13,418 cubic feet per acre for natural) because natural regeneration was predominantly western hemlock, a species with faster rates of volume production in this general area.

Introduction

The first extensive plantings of coast Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco var. *menziesii*) were accomplished by the USDA Forest Service in 1927 at three locations in western Washington. The planting near Sequim is in the Snow Creek drainage, a several thousand-acre area mostly clearcut between 1917 and 1919, then swept by wildfire in 1924 and 1925. Before logging, foresters mapped this area as mature and immature Douglas-fir and western redcedar (*Thuja plicata* Donn ex D. Don) forest types. The existence of naturally regenerated stands adjacent to these 1927 and later plantations provided the opportunity for quantitative comparisons of current yields in planted vs. naturally regenerated stands. Such comparisons are limited (Miller and others 1993) yet necessary in the continuing debate about plantation forestry.

We compared characteristics of planted and naturally regenerated stands based on matched, adjacent plots at six locations where clearcutting and wildfire occurred more than 66 years earlier. We compared length of establishment period and site index along with number of stems, diameter distributions, and stand volume by species.

Methods

Stand Locations and Treatment Histories

We used historic maps of planting and railroad logging routes to locate adjacent planted and naturally regenerated stands (fig. 1). Because the Douglas-fir plantations were more uniform in spacing and species composition than naturally regenerated stands (fig. 2), we could precisely delineate original planting boundaries. At six locations, we installed a 0.25-acre plot in both stand types after matching potential plot areas for comparability of slope, aspect, soil, and logging disturbance (table 1). The two plots at each location were 100 to 150 feet apart. All plot locations have poor to average site index. The original logging slash at these locations was burned by wildfire in 1924 and 1925. Planting occurred 2 to 3 growing seasons after wildfire in July 1925 (table 2). The seed source for planted stock is unknown and presumably collected below 1,500-foot elevation near Roy, Washington.

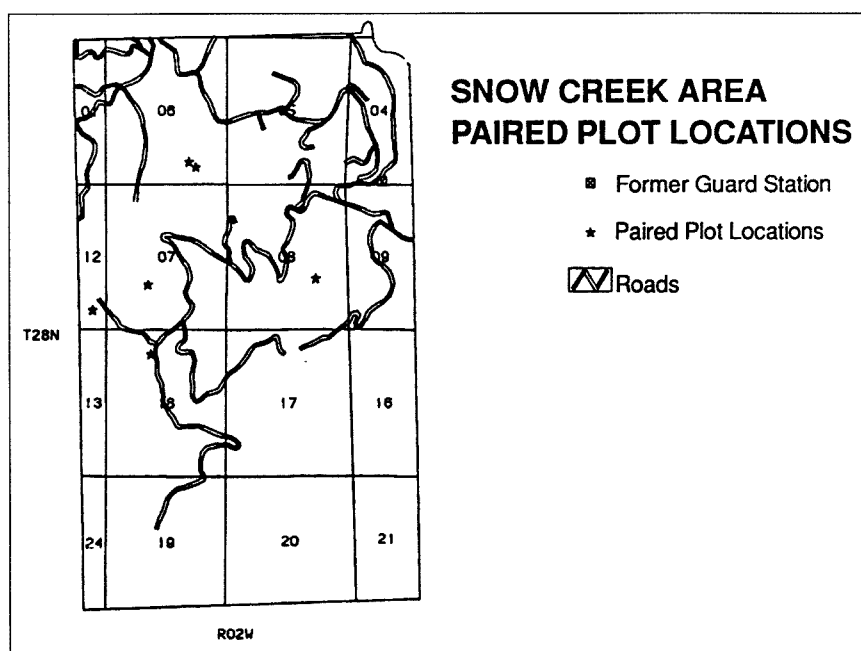


Figure 1—Location of study sites.



A



B

Figure 2—At stand age 65, tree spacing was more uniform in planted stands (A) than in naturally regenerated (B), and forest type was Douglas-fir instead of western hemlock (location 5).

Field Procedures

We measured d.b.h. of all live trees, 1.6-inches d.b.h. and larger, and also measured dead trees exceeding about 6 inches that had died or been wind-thrown in the past few years. We measured total height of 17 to 21 trees per plot of the primary species; d.b.h. of two-thirds of these trees exceeded the average d.b.h. of all trees on each plot. These trees were systematically chosen from tree enumerations. For the secondary species, we measured heights of two to eight trees per plot, all of large d.b.h. Heights of nine large western redcedar were measured in two plots, with this as a tertiary species.

Sampling for site index was from among the 40 largest Douglas-fir and western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) per acre (by d.b.h.). We bored these largest and undamaged trees for breast height (b.h.) age and measured each for total height; these five to six site trees per plot contributed to the height sample. We also bored three to five Douglas-fir per naturally regenerated plot to compare age and site index of this species with those of the primary species, hemlock, and the planted Douglas-fir nearby.

Table 1—General site description and treatment history

Area	Year ^a	Planting ^b		Elevation	Slope	Aspect	SI ₅₀ ^c	
		Stock	Density				P	N
			<i>Number per acre</i>	<i>Feet</i>	<i>Percent</i>		<i>Feet</i>	<i>Feet</i>
1	1928	2-1	635	2,380	5	NE	103	100
2	1928	1-1	645	2,330	10	E	113	96
3	1928	2-1	635	2,500	10	NE	111	95
4	1927	2-0	?	1,750	5	N	134	128
5	1928	1-1	645	1,875	5	SE	117	108
6	1928	1-1	645	1,850	5	E	125	114

^a After growing season of specified year.^b As documented in original planting records.^c Current stand; Douglas-fir site index at 50 years (King 1966); P = planted, N = naturally regenerated.**Table 2—Average breast-height (b.h.) age of Douglas-fir and estimated years to attain b.h. after burning at 6 locations by regeneration method**

Location	Time since				Age at breast height ^a			Time to reach breast height ^b		
	Burning	Planting	Nursery seeding	Delay in planting	Planted	Natural ^c		Planted	Natural ^c	
						DF	WH		DF	WH
Years										
1	66	63	66	3	57	53	53	9	13	13
2	66	63	65	3	57	54	54	8	12	12
3	66	63	66	3	51	52	52	14	14	14
4	66	64	66	2	57	54	54	9	12	12
5	66	63	65	3	57	56	58	8	10	8
6	66	63	65	3	57	51	52	8	15	14
All:										
Mean	66.0	63.2	65.5	2.8	56	53	54	9	13	12
SD ^d	—	—	—	—	2	2	2	2	2	2

^a After 1991 growing season.^b Planted = years since seeding in nursery; natural = years since burning (and assumed seeding).^c DF = Douglas-fir and WH = western hemlock.^d SD = standard deviation.

Data Analysis

We calculated total bole volume in cubic feet inside bark, including top and stump (CVTS), from regional volume equations and tariff-d.b.h. equations for the appropriate species. Equations to estimate CVTS included those for Douglas-fir (Bruce and DeMars 1974), hemlock (Wiley and others 1978), and western redcedar (Browne 1962). After initially developing and comparing tariff-d.b.h. equations for each species and plot, we calculated a pooled equation for hemlock and one for Douglas-fir at each location to increase sample size in both species. We used the same volume equation for western redcedar at all locations, however. We did not deduct volume for decay or top breakage when estimating volume of live and recently dead trees. Because no mortality data were collected before 1991, our data underestimated cumulative gross volume growth.

This is a retrospective study because treatment (regeneration) occurred in the past and the results are available in the current stand. The study consisted of paired stands, one planted and the other naturally regenerated, at six locations. We expressed response variables as a difference at each location; for example, volume on the planted plot minus volume on the naturally regenerated plot. We used Student's paired t-statistic to test the null hypothesis that the mean difference between planted and naturally regenerated stands at all locations was zero. We judged significance of all tests at $\alpha = 0.10$; actual p-values are provided so readers can make their own inferences.

Results **Years to Attain Breast Height**

Despite an average 2.8-year delay in planting after wildfire, Douglas-fir crop trees on planted plots averaged 56 years b.h. age compared to 53 years for Douglas-fir crop trees in the naturally regenerated stands (table 2). Assuming that seed from natural origins germinated in the 1926 growing season (after the July 1925 fire), Douglas-fir crop trees in the planted stands attained b.h. 4 years sooner than did Douglas-fir in the naturally regenerated plots (9 vs. 13 years from seed) and 3 years sooner than hemlock crop trees (table 2).

Tree Height and Site Index

Although Douglas-fir crop trees in planted plots originated from an off-site seed source, they averaged 32 feet taller (table 3) and 4 years older at b.h. than those on the naturally regenerated plots. Consequently, Douglas-fir site index (current b.h. age and height of the 40 largest trees per acre projected to an estimated height at 50 years, King 1966) averaged 117 feet or 10 feet greater in planted than in naturally regenerated stands ($p \leq 0.01$, table 3). Hemlock site index (Wiley 1978) averaged 102 feet at 50 years index age.

Number of Trees

At 65 to 66 years from seed, and initial planting densities of 635 to 645 trees per acre, planted stands averaged 184 more live Douglas-fir per acre but 213 fewer hemlock; these differences were statistically significant (table 3). When all species were pooled, however, number of live trees did not differ between planted and naturally regenerated stands (511 vs. 531 trees per acre, respectively). Planting clearly increased average number and proportion of Douglas-fir, yet natural regeneration of hemlock contributed strongly to plantation stocking, especially in smaller trees (fig. 3). Natural regeneration of Douglas-fir averaged only 41 trees per acre in the naturally regenerated stands (table 3). Uniform tree spacing in the planted stands suggests similar or fewer volunteers in these adjacent stands. In the 2 to 3 years before our measurements, more trees died in the plantation than in the naturally regenerated stand, but this recent mortality was only about 2 percent of live stem numbers and volume.

Table 3—Average live-stand statistics by regeneration method for trees 1.6 and 7.6 inches diameter at breast height and larger, on a per-acre basis

Characteristic	Regeneration method				
	Mean		Difference		
	Planted	Natural	Mean	SE ^a	p-value
<i>40 largest trees by d.b.h.</i>					
Height (feet):					
Douglas-fir	123	91	32	18	0.14
Hemlock	92	104	-11.8	8.8	.24
<i>1.6-inch and larger trees</i>					
Site index (feet):					
Douglas-fir	117	107	10.3	2.2	<.01
Hemlock	—	102	—	—	—
Stems (no.):					
All species	511	531	-20	45	.68
Douglas-fir	225	41	184	32	<.01
Hemlock	145	357	-213	58	.02
Diameter at breast height (inches): ^b					
Douglas-fir	14.5	17.6	-3.1	1.2	.05
Hemlock	7.1	10.6	-3.5	1.2	.03
Volume (cubic feet):					
All species	13,162	13,418	-256	786	.76
Douglas-fir	11,165	2,657	8,508	1,138	<.01
Hemlock	1,448	9,424	-7,976	1,195	<.01
Relative density:					
All species	95	98	-3	5	.51
Douglas-fir	66	—	—	—	—
<i>7.6-inch and larger trees, to 4.0-inch top</i>					
Volume (cubic feet):					
All species	11,832	11,624	209	826	.81
Douglas-fir	10,631	2,541	8,090	1,079	<.01
Hemlock	1,000	8,130	-7,130	1,102	<.01

^a SE = standard error.

^b Quadratic mean d.b.h.

Diameter Distributions in Live Stand

Douglas-fir averaged 14.5 inches d.b.h. in planted stands and 17.6 inches d.b.h. in naturally regenerated stands. The difference was statistically significant ($p \leq 0.05$). Hemlock averaged 7.1 inches d.b.h. in planted stands and 10.6 inches d.b.h. in adjacent naturally regenerated stands; this difference also was significant ($p \leq 0.03$). Planted stands averaged a larger proportion and greater number of trees in the 11-through 20-inch d.b.h. size classes (fig. 3). All trees in the 20-inch and larger d.b.h. class were Douglas-fir, regardless of regeneration method.

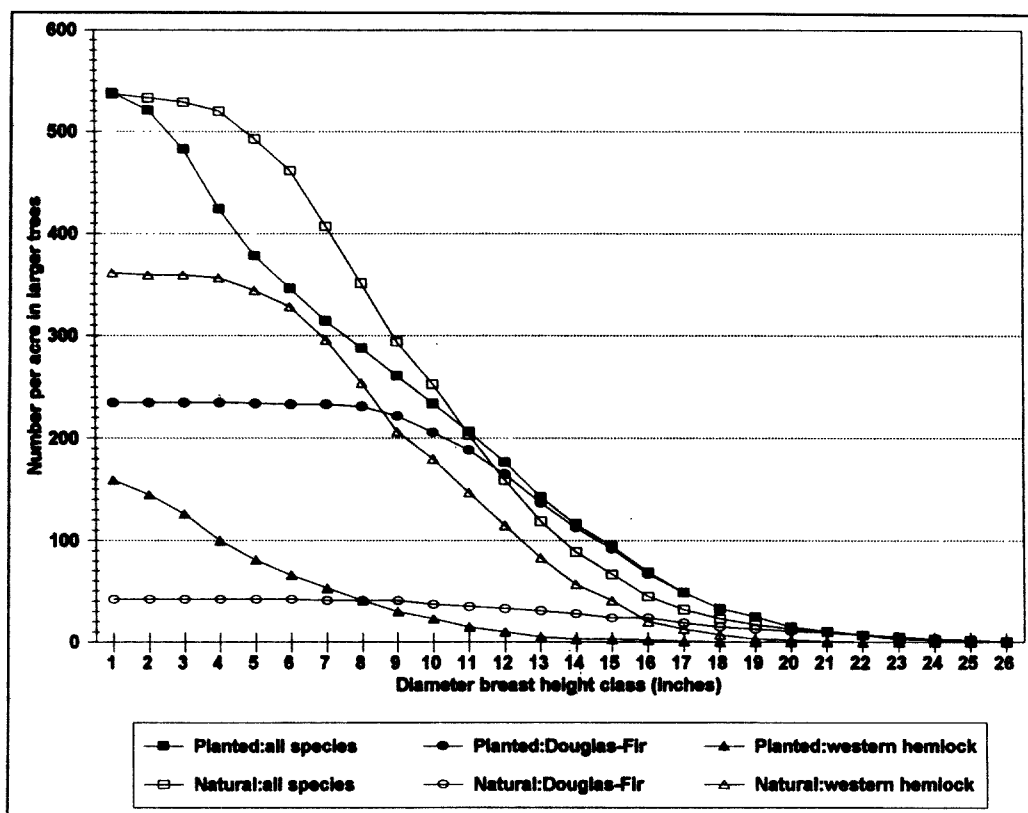


Figure 3—Number of trees of specified d.b.h. and larger, by species and stand origin.

Stand Volume and Relative Density

Live stand—At about 65 years from seed, total live volume in planted stands averaged 13,162 cubic feet per acre (table 3). Planted stands and naturally regenerated stands did not differ in total live volume of all trees 1.6 inches in d.b.h. and larger, and of trees 7.6 inches in d.b.h. and larger (table 3). About 85 percent of live volume in the planted stands was Douglas-fir, and 11 percent was hemlock. Conversely, in naturally regenerated stands, 70 percent of the live stand volume was hemlock and about 20 percent was Douglas-fir, which also contributed the largest trees in the naturally regenerated stands (table 3). Western redcedar was in both stand types. Based on all species, relative density (Curtis 1982) averaged 95 in the planted and 98 in the naturally regenerated stands, a nonsignificant difference (table 3). Relative density of Douglas-fir in planted stands, however, averaged 66.

Mean annual rates of net volume production—Mean rates of net CVTS production of all trees were similar on planted and naturally regenerated stands (table 4). Expressed as mean annual increment (M.A.I.) by all species since logging and the 1925 wildfire, net annual production in planted stands (199 cubic feet per acre) averaged 2 percent less ($4 \text{ ft}^3 \cdot \text{acre}^{-1} \cdot \text{yr}^{-1}$) than in naturally regenerated stands (table 4). Most volume production was by Douglas-fir in the planted stands and by hemlock in the naturally regenerated stands. Mean annual rates of volume growth also can be calculated by using years since planting (63 years) instead of years

Table 4—Average mean annual increment (M.A.I.) by regeneration method and species for trees of specified minimum diameter at breast height and larger, per-acre basis^a

Trees 1.6 inches and larger	Statistics by regeneration method				
	Mean		Difference		
	Planted	Natural	Mean	SE ^b	p-value
<i>Cubic feet per year</i>					
Since wildfire (site M.A.I.): ^c					
All species	199	203	-4	12	0.76
Douglas-fir	169	40	129	17	<.01
Hemlock	17	143	-120	18	<.01
Since planting (stand M.A.I.): ^d					
All species	208	203	5	13	.69
Douglas-fir	177	40	136	18	<.01
Hemlock	23	143	-120	18	<.01

^a M.A.I. = mean annual increment = cumulative volume of live and recently dead trees measured in 1991 divided by years since burning or planting.

^b SE = standard error.

^c Site M.A.I. = cumulative volume divided by 66 growing seasons after burning.

^d Stand M.A.I. = cumulative volume divided by growing seasons after planting.

since the sites were available after the 1925 wildfire (66 years, table 2). This calculation produces a "stand" M.A.I. of 208 cubic feet per acre for planted stands, which averaged 2 percent more ($5 \text{ ft}^3 \cdot \text{acre}^{-1} \cdot \text{yr}^{-1}$) than the 203 cubic feet per acre for naturally regenerated stands (table 4).

Although mortality volume was not measured until 1991, earlier mortality volume probably was minimal because trees were small and these stands were not grossly overstocked. For both planted and naturally regenerated stands, cumulative gross volume production probably was about 10 percent greater than net.

Discussion

Although most timber in the Snow Creek and associated drainages had been clearcut and extracted by railroad before the 1924 and 1925 wildfires, patches of uncut trees survived the fires to provide seed for natural regeneration. The utility of these seed sources was recognized in selecting areas for planting: "Uncut timber bordering cut-over land is expected to reseed to a distance of 1,000 feet. Groups of several seed trees of fair quality and well located on high ground are expected to care for the surrounding land to a distance of 500 feet. Single trees, those of poor quality, or poorly located as when within the creek canyon, are restricted to 200 feet effective seeding range. The boundaries as shown on the map may need to be varied somewhat, but in the main it is believed that the distance specified above should govern."¹

¹ Kummel, Julius F. 1927. Planting survey of the Snow Creek cut-over area, Olympic Forest. USDA Forest Service, Pacific Northwest Region. 6 p. Unpublished administrative report. On file with: Quilcene Ranger District, P.O. Box 280, Quilcene, WA 98376.

Our breast-high borings indicated that naturally regenerated crop trees averaged 3 to 4 years longer from seed to a 4.5-foot height—assuming seedfall and successful germination in spring 1926. Naturally regenerated Douglas-fir and western hemlock both achieved the 4.5-foot height in about the same time after the 1925 fire (13 vs. 12 years, respectively). Our sample of crop trees indicated that few, if any, advance regeneration survived the 1924 and 1925 fires; only 1 of 59 increment cores in naturally regenerated plots had closely spaced growth rings near the pith.

Planting and stocking records suggest that initial survival of planted seedlings was comparable to current standards, despite delayed planting and no management of competing vegetation. At 66 years after wildfire, planted and natural stands averaged 511 and 531 live stems per acre, respectively, thereby indicating that both natural seeding and planting in these locations were successful.

Because of the close proximity of the matched plots, we assume that natural seed-fall in the 2 to 3 years between the 1925 wildfire and planting was equal in amount and timing in both naturally regenerated and subsequently planted plots. Seedbed conditions for germination and early growth likely were comparable because we matched the plots for logging and fire history, slope, aspect, and soil conditions. Without thinning or stocking control, natural regeneration ultimately resulted in a hemlock forest type admixed with about 8 percent Douglas-fir and 25 percent western redcedar trees. The greater proportion of hemlock trees in the naturally regenerated stands may have resulted from more frequent periodicity of seed crops and the greater distance of seed dispersal characteristic of western hemlock (Ruth and Harris 1979). On planted plots, western hemlock and western redcedar each contributed about 28 percent to total stem numbers after 66 years. Hence, successful planting did not result in monoculture. The regularity of Douglas-fir spacing in the plantations indicated that most of that species were planted; we assume that natural regeneration contributed about 41 stems per acre (same as in natural stands) or 18 percent of the total number of Douglas-fir in the planted stands.

Productivity Differences

Much of the productive potential in the Snow Creek area probably was captured by successful establishment of uniform, fully stocked stands by both planting and natural regeneration. Dominant trees in planted stands averaged significantly greater height and 50-year site index than adjacent naturally regenerated Douglas-fir. Hence, potential concern about poor performance by off-site seed sources was not justified. In the naturally regenerated stands, site index of Douglas-fir (107 feet) averaged more than that of hemlock (102 feet). Steinbrenner (1976) reported similar findings for naturally regenerated stands of these two species in the glacial Puget Sound area and other portions of western Washington. Handley (1976) also reports that site index for Douglas-fir was greater than that of western hemlock where both species grow in mixture in British Columbia. Thus in general, Douglas-fir crop trees are taller than associated western hemlock at 50 years, the index age.

Although commonly used as a measure of site productivity, site index is an indirect and imprecise estimator of productivity because it fails to indicate the contribution of tree numbers and diameter to volume production. A more direct measure of stand productivity and commercial value is volume production by all trees or those exceeding some minimum diameter, at a specified reference age. At these study sites, volume production was similar in naturally regenerated stands and adjacent planted stands, although benefits of planting were probably reduced because planting was

delayed by 2 to 3 years after burning (table 2). Such delays allow greater competition from other vegetation. Natural regeneration resulted in hemlock stands that, on mesic sites like the Snow Creek area, have faster rates of volume production than do Douglas-fir. This has been ascribed to (1) greater density of trees (Handley 1976, Wiley 1976) and (2) about 10-percent greater underbark volume in individual trees of the same d.b.h. and height (Wiley 1976). Hence, our comparison of yields of planted vs. naturally regenerated stands was confounded by differing species composition. We could only compare yields in a Douglas-fir forest type with yields of a hemlock type having inherently greater yields. For the general location and site indexes of these study plots, one can estimate from Handley (1976) and Steinbrenner (1976) that naturally regenerated stands of hemlock could produce 10- to 40-percent more cubic volume than naturally regenerated Douglas-fir could produce. We speculate therefore that volume yields of planted Douglas-fir probably would exceed those of naturally regenerated Douglas-fir at Snow Creek.

In the Cascade Range of western Washington and Oregon where Douglas-fir regenerates naturally, volume yields are consistently greater in Douglas-fir plantations. For 35- to 38-year-old Douglas-fir plantations in western Washington and Oregon, Miller and others (1993) reported that live tree volume (1.6 inches d.b.h. and larger) of all species and of Douglas-fir averages 40 percent greater on planted plots. Volume of live conifers 7.6 inches d.b.h. and greater averages 41 percent greater on planted plots as compared to naturally regenerated plots (2,977 vs. cubic 2,118 feet per acre). For former farmland in southwestern Washington, Murray and Harrington (1990) reported that bole volume of three 24- to 27-year-old Douglas-fir plantations was 40 to 57 percent greater than that simulated by DFSIM (Curtis and others 1981) for trees 1.6 inches d.b.h. and larger. For trees 7.6 inches d.b.h. and larger, volume per acre was 85 to 151 percent greater than simulated yields. Although DFSIM predictions are based on data from an extensive sampling of stands in the Douglas-fir region, about two-thirds of the data originated from naturally regenerated stands. The comparison then is planted (on farmland) vs. simulated averages for natural and some planted stands.

According to the following tabulation, yields measured in the Snow Creek plantations are similar to those projected by DFSIM for Douglas-fir plantations without thinning (Curtis and others 1981: p. 19, 20) for the same total age (65 years) and two site indexes, bracketing SI 117:

Source	Site index	Volume, by species, in trees exceeding			
		1.5 inches in d.b.h.		7.5 inches in d.b.h.	
		All	Douglas-fir	All	Douglas-fir
	<i>Feet</i>				
This study	117	13,162	11,165	11,832	10,631
DFSIM	105	9,823	—	9,165	—
DFSIM	125	13,181	—	12,480	—

These similar stand volumes, however, are distributed on a twofold greater number of trees in our study areas. Not only was initial planting density greater at Snow Creek (635 to 645 seedlings per acre) than that assumed in DFSIM (400 per acre), but residual density at age 65 years in the Snow Creek plantations averaged 225 per acre of Douglas-fir and 286 per acre of other species compared to 245 per acre (SI 105) and 200 per acre (SI 120) of all species. Because of their small size, the large number of other species in the Snow Creek plantations accounted for only 10 to 15 percent of the total stand volume (table 3).

Conclusions

Data from our six study locations indicated that planting resulted in a Douglas-fir stand type, in which about 15 percent of the current volume at age 65 years is western hemlock and 4 percent is western redcedar from natural origin. By incurring planting costs (rather than relying on natural regeneration), foresters secured more Douglas-fir but did not create a monoculture. Natural regeneration resulted in hemlock type in which about 20 percent of the current volume is Douglas-fir and 10 percent is western redcedar. Naturally regenerated Douglas-fir were the largest trees in the hemlock stand. Yet, these Douglas-fir (40 largest per acre) were shorter and smaller than those in the planted stand despite the offsite seed source of the latter. Because of more rapid height growth, site indexes averaged about 10 percent greater in planted than in naturally regenerated stands. Planting did not result in greater volume production, however, because natural regeneration was predominantly western hemlock, a species with faster rates of volume production in this general area.

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Metric Equivalents

When you know:	Multiply by:	To find:
Inches (in)	2.54	Centimeters
Feet (ft)	0.305	Meters
Acres (acres)	0.405	Hectares
Cubic feet per acre (ft ³ /acre)	0.070	Cubic meters/hectare

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Tree numbers, height, and volume were determined in six 63- to 66-year-old plantations of coast Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco var. *menziesii*) in northwest Washington. These stands resulted from the first extensive plantings of this species in the Pacific Northwest. Data from 0.25-acre plots in these plantations were compared to those from matched plots in adjacent, naturally regenerated stands with the same history of logging, wildfire, and absence of further silviculture after regeneration. Planting resulted in well-stocked Douglas-fir stands with volunteers of other tree species. Natural seeding resulted in similarly stocked stands of western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) with Douglas-fir in the dominant crown class. Average live volume was similar in both stand types; only the proportion by species differed. Mean annual rate of volume growth since planting averaged 208 cubic feet per acre, which averaged 2 percent more than in adjacent natural stands.

Keywords: Douglas-fir, western hemlock, western redcedar, planting, natural regeneration, yields, site index.

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