Early Development of Matched Planted and Naturally Regenerated Douglas-Fir Stands After Slash Burning in the Cascade Range

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ABSTRACT. *We compared matched planted and naturally regenerated plots in 35- to 38-year-old Douglas-fir (*Pseudotsuga menziesii *var.* menziesii*) stands at seven locations in western Washington and Oregon. Total number of live stems is similar, but stands planted to Douglas fir average 26 more live stemslac of Douglas-fir and 39 fewer stems lac of other conifers than do naturally regenerated stands. Despite an average 2-yr delay in planting after burning, dominant Douglas fir in planted stands average 3 fewer years than natural regeneration to attain breast height after burning. Volume of all live trees (1.6 in. dbh and larger) and of Douglas fir average 40% greater on planted plots. Volume of live conifers 7.6 in. dbh and greater average 41 % greater on planted plots as compared to naturally regenerated plots (2977 vs. 2118 ft 3 lacy. Differences that developed on these plots are probably less than differences that would be shown by plantations being established today with prompt planting and improved nursery stock and planting methods. Planting slashburned clearcuts in this general area of the Cascade Range resulted in faster volume production. West. J. Appl. For. (8) 1: 5-10.*

Until the 1940s, reforestation of cutover land in the Pacific Northwest primarily relied on natural regeneration. Many areas, however, did not regenerate satisfactorily (Isaac 1938, Munger and Matthews 1941). In recent decades, most clearcuts have been planted. Attainment of improved yields has been assumed, when sites are prepared to provide a favorable seedling environment and when healthy seedlings of the appropriate seed source are planted. Rigorous tests of this assumption, however, have not been reported for Douglas-fir (*Pseudotsuga menziesii* var. *menziesii*) in controlled field trials with quantitative comparisons of survival and growth of adjacent, planted vs. naturally regenerated, stands.

This paper compares characteristics of planted and naturally regenerated stands on matched plots at seven slashburned clearcuts in the Cascade Range of western Oregon and Washington. Coast Douglas-fir is the primary species in these stands. We compare 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

To investigate effects of burning slash after harvest of oldgrowth forests, Morris (1947) installed a burned and an unburned plot on about 75 clearcuts in western Washington and Oregon between 1946 and 1952. Nearly all plot-pairs were naturally regenerated (Morris 1970). In 1986, at seven locations, we established a new plot in an operational planting of Douglas-fir and within 130 ft of the original, naturally regenerated burned plot (Figure 1). Plots varied in size (0.24 to 0.45 ac), but both planted and naturally regenerated plots at each location were similar in size, and were matched for plant community and comparability of slope, aspect, soil, and logging disturbance (Table 1). All locations have summer drought and poor to average site index. Slash at these locations had been burned in the fall within 2 growing seasons after logging, presumably under a variety of fuel and moisture conditions (Table 2). Planting occurred 0-6 growing seasons after slash burning.

Field Procedures

We measured dbh of all live and recently dead trees, 1.6 in. dbh and larger. We also determined diameters and species of stumps in two locations that had been precommercially thinned (Table 1). We measured total height of 25 trees per plot of the
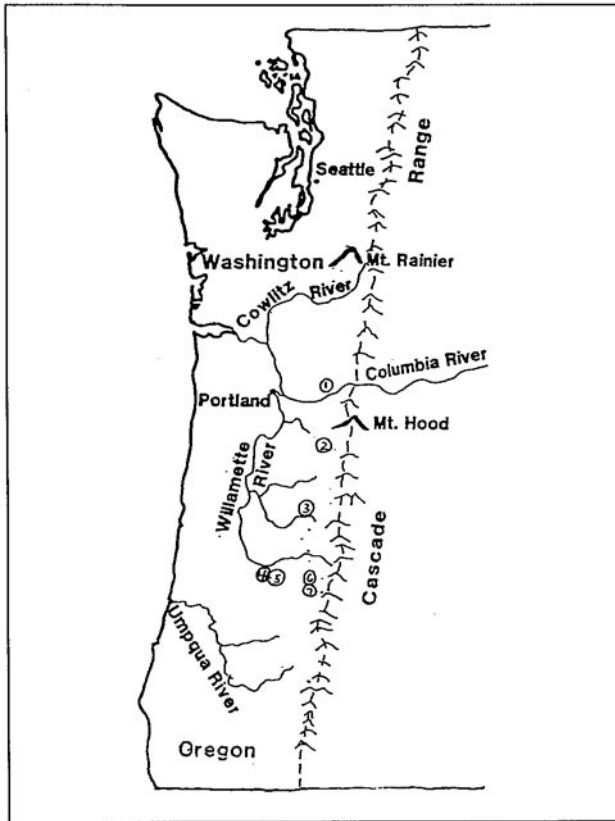
Figure 1. Location of study sites.

primary species (Douglas-fir); dbh of 18 of these trees exceeded the average dbh of all trees on the, plot. For each associated species contributing 20% or more of the total basal area, we measured heights of 15 trees per plot.

Sampling intensity for site index was equivalent to the 40 largest (by dbh) Douglas-firs per acre. Thus, we subdivided each plot into 1/40-ac portions, bored at breast height the largest undamaged Douglas-fir in each portion for age, and measured each for total height; these 8-20 heights per plot contributed to the 25-tree height sample for each plot.

Data Analysis

We calculated total stem volume in cubic feet, including top and stump, from height-dbh equations and regional volume equations for the appropriate species. We developed

height-dbh equations for each species and each plot, either from data available from that plot or drawn from another plot or from regional equations (Larsen and Hann 1987). We did not attempt to calibrate any of these transported equations to the subject plot. Equations to estimate total bole volume including stump and tip, included those for Douglas-fir (Bruce and DeMars 1974),western hemlock (Tsuga heterophylla) (Wiley et al.1978), and other species (Browne 1962). Volume equations were not available for some species, mostly hardwoods, so we used equations for related species. We estimated volume of thinned trees by converting stump diameter to dbh (Curtis and Amey 1977) and then using appropriate height-dbh equations and regional volume equations. We did not deduct for decay or top breakage. For stand volume and numbers of trees, we compared both current standing and cumulative, including recent mortality and trees felled in thinning. We estimated cumulative gross volume growth as the total of live, recently dead, and cut trees. We probably underestimated mortality volume, hence cumulative gross volume growth, because no mortality data were collected before 1986.

The experimental design was a paired-plot comparison, with one pair at each location. Consequently, no statistically supported statement is possible about planted vs. natural at a single location. We expressed response variables as a difference at each location-for example growth on the planted plot minus growth on the naturally regenerated plot. We used Student's t-statistic to test the null hypothesis that the mean difference between plots at all locations was zero. We judged significance of all tests at $P < 0.10$ using SPSS programs (Norusis 1986) for statistical analyses; yet we provide actual P-values so readers can make their own inferences.

Results

The seven locations sample central portions of the Cascade Range in western Washington and Oregon (Figure 1). The sampled stands represent successful plantations of that era; local foresters verified that seed for the planted stock was from local, naturally regenerated stands and that planting records and current stands indicated successful plantings. Several potential locations were rejected because these two criteria were not fulfilled.

Table 1. General site description and treatment history.

Area	Forest Service District	Elev (ft)	Slope (%)	Aspect	Forest zone[1]	Plant assoc.[2]	SI₅₀[3] (ft)	Date burned	Stocked[4] (%)	Treatment Herbicide	Thinning
1	Wind River	1800	20	S	ABAM	GASH	88	Oct. 1950	92		—
2	Estacada	2100	23	W	TSHE	RHMA-GASH	118	Oct. 1951	72	1967	1966
3	Blue River	2300	12	NE	TSHE	RHMA-GASH	122	Oct. 1951	84	—	1964, 1974
4	Lowell	2750	19	NE	TSHE	POMU	121	Fall 1948	88	—	—
5	Lowell	3500	13	N	TSHE	RHMA-OXOR	103	Sept. 1949	92	—	—
6	Oakridge	2900	7	S	TSHE	RHMA-BENE	116	Oct. 1949	64	—	—
7	Oakridge	3200	2	SW	TSHE	RHMA-BENE	114	Fall 1950	88	—	—

[1] ABAM = Pacific silver fir zone, TSHE = western hemlock zone.
[2] Determined from Hemstrom et al. (1982). GASH = *Gaultheria Shallon*, salal; POMU = *Polystichum munitum*, sword fern;
OXOR = *Oxalis oregana*, oxalis; RHMA = *Rhododendron macrophyllum*, rhododendron; BENE = *Berberis nervosa*, Oregon-grape.
[3] Douglas-fir site index at 50 yr (King 1966) on the naturally regenerated plot.
[4] 1962 stocking on 25 0.004-ac subplots in the naturally regenerated plots; trees 6 in. and taller were counted.

Table 2. Average breast-height (bh) age and years to attain bh after burning at seven locations, by regeneration method.

Location	Time since logged	Time since burned	Time since planted	Delay in planting	Age at bh[a] Planted	Age at bh[a] Natural	Time to reach bh[b] Planted	Time to reach bh[b] Natural
1	36	36	36	0	29	28	7	8
2	35	35	35	0	28	25	7	10
3	37	35	34	1	28	25	6	10
4	39	38	38	0	27	27	11	11
5	38	37	33	4	28	27	5	10
6	37	37	35	2	26	25	9	12
7	37	36	30	6	24	24	6	12
All:								
Mean	37	36	34	2	27.1	25.9	7.3	10.3
SE	—	—	—	—	(0.6)	(0.6)	(0.9)	(0.6)
Diff.					1.3 (0.5)			
$P \le$					0.04			

[a] After 1986 growing season
[b] Planted = years since planting; natural = years since burning

Time to Attain Breast Height

Trees in naturally regenerated plots took about twice as long to reach breast height as reported for other areas with the same site indexes (King 1966). Despite an average 2-yr delay in planting after burning, crop trees (largest 40/ac) on planted plots attained breast height 3.0 yr sooner than did those in the naturally regenerated plots (7.3 yr vs. 10.3 yr) (Table 2).

Site Index

Douglas-fir site indexes (current height of the 40 largest trees per acre projected to an estimated height at 50 yr) were similar in planted and naturally regenerated stands (Table 3). Crop trees planted on plots averaged 2.7 ft taller (Table 3) and 1.3 yr older at breast height than those on the naturally regenerated plots.

Number of Trees

Live Stand. In 1986, planted stands averaged 26 more live Douglas-firs per acre but 39 fewer other conifers; these differences were statistically significant (Table 3). Average number of live hardwoods or live trees of all species did not differ significantly. Mortality and precommercial thinning (at two locations) in the previous decade reduced stem numbers about 20%, but these actions had little effect on species composition.

Cumulative Numbers. In cumulative numbers (live + cut + recently dead), planted stands averaged 6% more Douglasfir but 47% fewer conifers other than Douglas-fir (Table 4). Thus, planting Douglas-fir only slightly increased the average number and proportion of Douglas-fir that established at these

Table 3. Average live-stand statistics by regeneration method for trees 1.6 in. and 7.6 in. dbh and larger, per acre basis.

Characteristic	Statistics by regeneration method						
	Planted Mean	Planted (SE)	Natural Mean	Natural (SE)	Difference Mean	Difference (SE)	$P\le$
			40 largest trees by dbh				
Ht (ft)	71.0	(3.2)	68.3	(2.4)	2.7	(3.6)	0.10
SI (ft)	112.7	(6.2)	111.7	(4.6)	1.0	(2.2)	0.67
			Trees 1.6-in. and larger				
Stems (no.)							
All species	438	(90)	453	(97)	-15	(30)	0.63
Douglas-fir	377	(67)	352	(65)	26	(27)	0.38
Other conifers	56	(29)	95	(39)	-39	(13)	0.03
Hardwoods	4	(2)	6	(6)	-2	(6)	0.71
Volume (ft^3)							
All species	2,977	(338)	2,121	(266)	856	(168)	0.01
Douglas-fir	2,925	(318)	2,105	(261)	820	(167)	0.01
Other conifers	52	(42)	16	(8)	36	(40)	0.40
Hardwoods	0	—	0	—	0	—	—
			Trees 7.6-in. and larger				
Volume (ft^3)							
All species	2,977	(338)	2,118	(267)	859	(167)	0.01
Douglas-fir	2,925	(318)	2,102	(263)	822	(166)	0.01
Other conifers	52	(42)	16	(8)	36	(40)	0.34
Hardwoods	0	—	0	—	0	—	—

Table 4. Average cumulative-stand statistics by regeneration method for trees 1.6-in. dbh and larger, per acre basis.[1]

Characteristic	Planted		Natural		Difference		P<
	Mean	(SE)	Mean	(SE)	Mean	(SE)	
Stems (no.)							
All species	519	(91)	554	(92)	-35	(56)	0.55
Douglas-fir	458	(68)	433	(57)	25	(46)	0.61
Other conifers	57	(29)	107	(41)	-50	(17)	0.03
Hardwoods	4	(2)	13	(6)	-9	(5)	0.11
Volume (ft^3)							
All species	3,369	(388)	2,736	(307)	903	(186)	0.01
Douglas-fir	3,527	(347)	2,632	(277)	895	(173)	0.01
Other conifers	104	(62)	85	(30)	20	(46)	0.69
Hardwoods	8	(4)	19	(15)	10	(13)	0.44
MAI (ft^3/yr)[2]							
All species	100	(10)	75	(8)	25	(5)	0.01
Douglas-fir	97	(9)	72	(7)	25	(8)	0.01

[1] Total of live, cut, and recently dead trees measured inn 1986 when stands averaged 24-29 yr at bh.
[2] MAI = mean annual increment = (cumulative volume)/(years since burning).

locations. Natural regeneration of Douglas-fir and other conifers may have contributed strongly to stocking in the planted stands. For example, the 1962 stocking survey on the naturally regenerated plots (10-13 yr after burning) showed 64% to 92% stocking (Table 1) or at least 160 to 230 well-spaced trees per acre. We assume that volunteers established at similar densities on planted plots.

Cumulative number of trees averaged 519/ac in planted plots and 554 in those regenerated naturally. Numbers of trees on planted plots differed from those on naturally regenerated plots only in having fewer conifers other than Douglas-fir

(Table 4). Because none of these stands ryas grossly over-stocked, we assumed that the total number of live, recently dead, and cut trees represented the cumulative number of trees surviving the seedling stage of stand development.

Diameter Distributions in Live Stand

Douglas-fir averaged 8.2 in. (SE = 0.4) dbh on planted plots and 7.6 in. (SE 0.4) on naturally regenerated plots. The difference was statistically significant (P < 0.04). Planted stands averaged a larger proportion and number of trees in the 6-in. through 13-in. dbh size classes (Figure 2). Nearly all trees in the 6-in. and larger .dbh class were Douglas-fir,
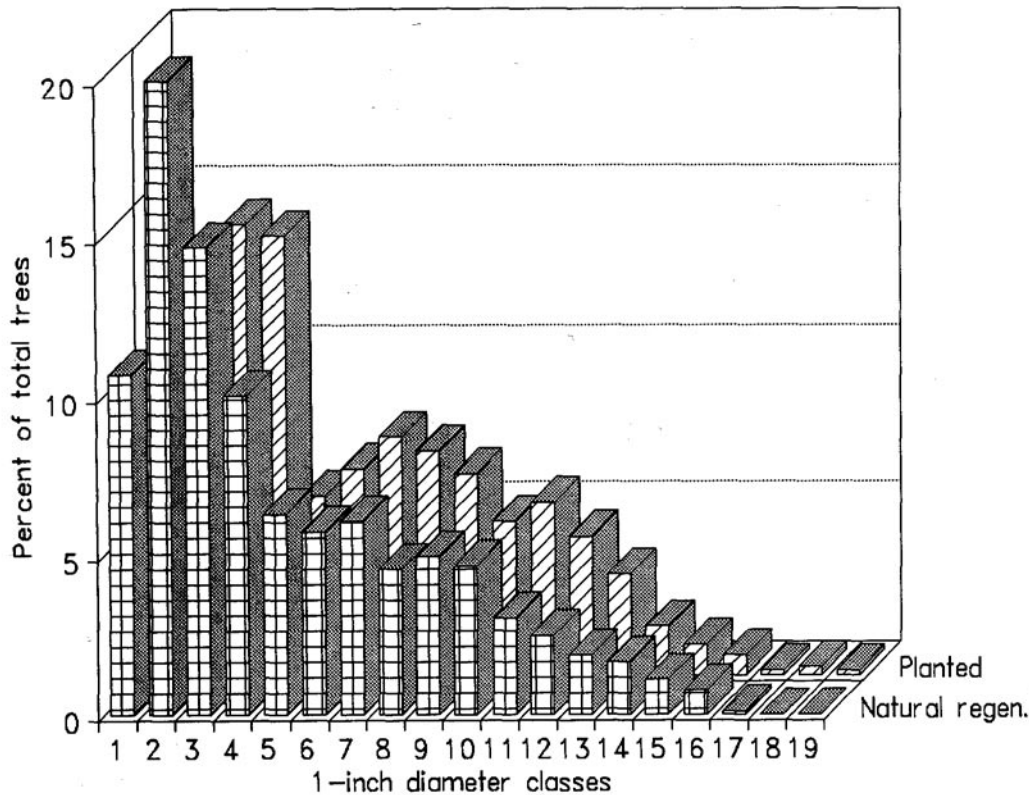
Figure 2. Size–class distribution of all species larger than l-in. dbh.

regardless of regeneration method. In 5-in. and lower dbh classes, naturally regenerated plots averaged more trees, especially western hemlock and western redcedar (Thuja plicata) as understory regeneration. Spatially, these small trees tended to be unevenly distributed.

Stand Volume

Live Stand. Planted stands averaged 40% (856 ft /ac) more live volume in trees 1.6 in. dbh and larger, and 41% (859 ft / ac) more in trees 7.6 in. dbh and larger. Nearly all of the additional volume was Douglas-fir (Table 3). Expressed as volume per tree, Douglas-fir on planted plots averaged 27% larger (7.6 vs. 6.0 ft^3). Trees in planted plots averaged 8% greater average diameter and 1% greater height (Table 3). Although numbers of trees were similar (Table 4), tree distribution appeared more uniform in planted plots.

Cumulative Gross Volume Production. Cumulative gross volume production of all species was also greater on planted plots (Table 4). Expressed as mean annual increment (MAI) since burning, production by all species on planted plots was 33% (25 ft^3 ac^{-1} yr^{-1}) greater than on naturally regenerated plots (Table 4); nearly all of this additional volume was in Douglas-fir.

For both planted and naturally regenerated stands, cumulative gross volume production was slightly underestimated because mortality volume was not measured until 1986. Because these stands were not overstocked, mortality in the first 2-3 decades was probably minimal; hence, this underestimation of mortality volume should not invalidate these comparisons.

Discussion

Capturing the full productive potential of a site requires prompt establishment of a uniform stand of trees. Initial spacing between trees affects growth and merchantable yields (Smith and Reukema 1986, Reukema and Smith 1987). They concluded that choice of initial spacing is one of the most important decisions by a stand manager and that initial planting of Douglas-fir at 12 to 15 ft (300-190 stems/ac) appears to be near optimum for most regimes to produce lumber. Closer spacings, however, produce more biomass at earlier ages.

Lesser bole volume (40%) on our naturally regenerated plots may in part be explained by regeneration lag. The largest (40/ac) Douglas-fir in these stands averaged 10.3 yr after slash burning to reach bh. Other trees probably had an even greater regeneration lag. Difference in dbh distributions of the main stand and the uneven spatial distribution of understory also support our theory that the naturally regenerated stands seeded in over a number of years. The unexpectedly extended period after burning for the largest 40 trees/ac to attain 4.5-ft height could have several explanations. For naturally regenerated plots, we suspect (1) delayed seedfall, and (2) slow height growth after germination, because unfavorable site conditions and competition retarded height growth. Explanations for planted plots include (1) delayed planting (Table 2), (2) poor condition of planting stock, as mentioned in reforestation

reports of some locations, and (3) slow height growth.

Except for Location 4, we consider the sample sites as difficult to regenerate. Shallow, coarse-textured soils make summer drought common on the Rhododendron-Oregon grape sites (Locations 6 and 7). These sites are also relatively cool, and competition from resprouting shrubs could have slowed seedling growth. Summer drought is also characteristic of the relatively warmer Rhododendron-salal sites (Locations 2 and 3). Drought, however, is probably less intense on the Rhododendron-oxalis site (Location 5) making conditions for natural regeneration more favorable. Location 1 is a transitional portion of the Pacific silver fir zone where silver fir (Abies amabilis), western hemlock, and limited Douglas-fir regenerate naturally. At Location 4, severe brush competition is an additional explanation for the lengthy regeneration period. Evidence from planting and stocking records suggest that survival of planted seedlings was often poor compared with current standards. At our study areas, planted and natural stands initially averaged at least 519 (SE=91) and 554 (SE=92) stems/ac, respectively (Table 4); to these estimates must be added some unknown number of trees that died about 10 yr before our measurements. Tree numbers indicate that natural seeding in these locations was successful.

Planted and naturally regenerated stands did not differ in average site index. Although commonly used as a measure of site productivity, site index is an indirect and imprecise estimator of stand 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. Volume production, however, was slower in naturally regenerated stands than in adjacent planted stands even though benefits of planting were probably reduced because planting was delayed by 1 to 6 yr after burning at four of these seven locations (Table 2). Such delays allow greater competition from other vegetation.

We found no additional published information to support or refute our findings that growth of planted stands of coast Douglas-fir exceeds that of naturally regenerated stands on slash-burned areas. For former farmland in southwestern Washington, Murray and Harrington (1990) report that bole volume of three 24- to 27-yr-old Douglas-fir plantations was 40-57% greater than those simulated by DFSIM (Curtis et al. 1981) for trees 1.6-in. dbh and larger. For trees 7.6 in. and larger, volume per acre was 85-151 % 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. Hence, their comparison is planted (on farmland) vs. simulated natural and planted stands. The authors suggested several possible reasons for enhanced yield of these plantations on former farmland: greater uniformity of site and tree spacing, early vegetation control through repeated cultivation, and assumed increased nutrient availability.

Our study is a side-by-side comparison of 35- to 38-yr-old planted vs. naturally regenerated stands originating after clearcutting. We also observed, but did not quantify, more

uniform spacing among planted trees. Vegetation control by herbicide was attempted at one of seven locations with unknown results. We measured greater yields on planted plots, although the volume gains were less than those reported for simulations by Murray and Harrington (1990).

Both planted and naturally regenerated stands in our study areas were established on slash-burned areas; we had no opportunity to compare growth of planted vs. naturally regenerated stands on unburned areas. Current management trends of avoiding slash burning or conducting light burns, however, emphasize the need for such comparisons. Results for naturally regenerated stands on matched plots (burned vs. unburned) at 44 locations in the Cascade Range of western Oregon and Washington showed that first slash burns generally affected species composition, but not the total amount of stem volume produced in the subsequent 40 yr (Miller 1989). Hence, we speculate that on unburned areas the potential for greater yields from planted stands would not be realized when: (1) advance regeneration would provide adequate stocking; (2) other conifers besides Douglas-fir were acceptable as crop trees; (3) much slash remained after harvest as barriers to planting; (4) minimal planting costs or effort was expended to ensure uniform and adequate survival of planted trees.

To summarize the results at our seven study locations, inherent site productivity, as measured by site index, did not differ among these matched plots. The greater volume production in planted stands is probably explained by different stand development resulting from spatial distribution, age structure, including earlier attainment of breast height, and species composition. This faster timber production was achieved by incurring planting costs, rather than completely relying on natural regeneration. Because of improved technology of artificial regeneration and availability of genetically selected seed, gains from current planting might be even greater than those reported here. Although not as quickly established or as uniformly distributed as planted trees, natural regeneration at these locations was successful. Costs, species choice, and other factors also must be considered when selecting a method for regeneration. Whatever system is selected, capturing the full productive potential of the site requires prompt establishment of a uniform stand of crop trees.

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