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Gross Yields for Even-Aged Stands of Douglas-fir and White or Grand Fir East of the Cascades in Oregon and Washington

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METRIC EQUIVALENTS

1 inch = 2.54 centimeters
1 foot = 0.304 8 meter
1 acre = 0.404 7 hectare
1 square foot/acre = 0.229 6 square meter/hectare
1 cubic foot/acre = 0.069 97 cubic meter/hectare

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GROSS YIELDS FOR EVEN-AGED STANDS OF DOUGLAS-FIR AND WHITE OR GRAND FIR EAST OF THE CASCADES IN OREGON AND WASHINGTON

REFERENCE ABSTRACT

Cochran, P. H.
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Equations and tables for predicting net and gross yields for Douglas-fir and white (grand) fir in even-aged stands east of the Cascade Range in Oregon and Washington are presented. Data were collected in stands where height growth apparently was never suppressed by competing understory vegetation, high density, or top damage once the heights of the dominants became greater than 4.5 feet.

KEYWORDS: Yield tables, yield table construction, increment (gross), increment (net), stem analysis, measurement systems, even-aged stands, Douglas-fir, *Pseudotsuga menziesii*, white fir, *Abies concolor*, grand fir, *Abies grandis*.

Research Summary

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Stem analyses of selected sample trees in temporary sample plots in even-aged stands were used to calculate gross periodic annual increments. Volume and basal area of the sample plots at the time of sampling were regarded as net volume and net basal area. Multiple regression methods were used to relate net basal area to site index and age at 4.5 feet. Then net volume and periodic annual increment were related to site index, age at 4.5 feet, and net basal area. Gross volume yield was obtained as a cumulative summary of gross volume increment from a breast-high age of 20 years plus the net volume at this age.

Introduction

Gross and net volume yield of Douglas-fir (*Pseudotsuga menziesii* (Mirbel) Franco) and white fir (*Abies concolor* (Gord. & Glend.) Lindl.) or grand fir (*Abies grandis* (Dougl.) Lindl.)[1] are given in total cubic feet of peeled volume for all stems 1.0-inch d.b.h. and larger. Gross yield represents all the bole wood produced and equals the net yield plus volume of the mortality. Thus, gross yield represents a potential value that intensive management can approach but never reach. Gross yield can be taken as an upper limit of yield in simulation models and as a guide that foresters can use to measure success of their own management practices.

Yields presented here are based on limited information. As more information becomes available, these yield tables should be revised. This information is presented now because no other yield information for these species in this geographical area is generally available. These yields are for even-aged stands where height growth has not been suppressed by overstory, competing understory vegetation, top damage, or high stand densities once the heights of the dominants in the stand become greater than 4.5 feet. This study was undertaken as part of the DFTM Expanded Research and Development Program to assess potential growth of healthy managed stands susceptible to tussock moth attack.

[1] An *Abies grandis*-*A. concolor* species complex is recognized in the central Oregon Cascade Range. More southerly populations resemble *A. concolor*, whereas populations to the north become steadily more like *A. grandis* (Zobel 1973). In this study no attempt was made to separate white and grand fir trees from each other or their hybrids. Data were handled as if they were one species.

Methods

This study was conducted by sampling temporary plots. Sampling objectives were: (1) to obtain a good geographic representation of these stands as they occur on various habitat types and soils east of the Cascades in Oregon and Washington and (2) to sample 10 stands for each 10-year age span from breast-high ages of 0 to 120 years. These 10 stands (4 pure Douglas-fir, 4 pure white (grand) fir, and 2 mixed Douglas-fir-white (grand) fir) were to represent the widest possible range in site quality. As explained in the "Results" section, these objectives were not completely met.

Circular 1/5-acre sample plots (1/10-acre plots if height of dominants was 30 feet or less) had the following characteristics:

1. Stands on the plots were single storied and had no old remnant trees. They were even aged; that is, the ages of the youngest trees at ground line were at least 80 percent as old as the oldest trees.
2. The crown canopy was closed or nearly closed at the time of sampling, but there was no evidence of mortality within the last 10 years. For some plots there was no evidence of mortality exceeding 5 percent of the current plot volume for a period back in time longer than 10 years.
3. Each plot had a buffer strip at least equivalent in width to tree height. Isolated clumps of trees were not sampled.

D.b.h. was measured for all trees, and 1-inch diameter class distributions for each species found were constructed for each plot. From 12 to 16 trees of each species were cut. The three largest diameter trees of each species were sampled, and four to six additional trees of each species were picked randomly from diameter classes larger than the mean diameter. One tree was randomly picked from the class containing the mean diameter and four or five more trees of each species were randomly picked from diameter classes smaller than the mean diameter. This method of picking sample trees was used because the larger trees have faster rates of growth than do smaller trees, and I wanted to determine past growth rates for the plot. If the tallest tree on the plot was not picked in this sampling process, it was felled and used in determination of site index curves (Cochran 1979a, 1979b) but not in determination of volume growth rates. Site index (tables 1 and 2) is defined as the height of the tallest tree on the plot at a breast-high age of 50 years (Cochran 1979a, 1979b). For mixed white (grand) and Douglas-fir plots, site indexes were determined for both species, and the highest site index determined for the plot was used regardless of species.

For plots that appeared to have little mortality in the past, a stem analysis was performed on each sample tree. Sample trees were sectioned at 1 foot, 4.5 feet, 10 feet, and then at 10-foot intervals up the stem unless dominant trees were shorter than 30 feet. For these younger stands, trees were sectioned a 5-foot intervals beyond 10 feet. Each section was measured so growth for successive 5-year periods back in time from the end of the 1975 growing season could be determined. Diameter measurements on each section were made on the longest and shortest radii through the center and averaged. Smalian's formula was used to determine volume of the bole segments above the stump for each period. The stump was considered a cylinder with the diameter determined at 1 foot. Tree volumes were the total of volumes of each segment, including the stump. Volume increment for any 5-year period was the difference in total volume at the start and end of the period.

Where there was evidence of mortality exceeding 5 percent of the current plot volume back in time beyond 10 years, only five of the sample trees (two large, two small, and one intermediate in size) were completely sectioned. For the remaining trees, heights at the end of 1975, 1970, 1965, and 1960 were determined by counting whorls and then cutting the stem and checking the age with a ring count. The 1-foot stump diameter outside bark was measured with a tape. Outside bark diameters at 10 feet and then at 5- or 10-foot intervals up the bole (depending on whether the height of the dominants was less or more than 30 feet) were measured with a caliper. Breast-high sections were removed and diameters determined for the end of 1975, 1970, 1965, and 1960. Equations were developed from trees sectioned at intervals relating bark thickness up the bole to bark thickness at breast height. These equations were used in the determination of inside bark volumes at the time of cutting for sample trees that were not sectioned. From the five trees sectioned at intervals on each plot, cylindrical form factors were determined for the time of sampling, and at the end of 1975, 1970, 1965, and 1960. Three separate linear regressions relating form factors in 1970, 1965, and 1960 to current form factors for the sectioned sample trees were calculated and used to determine form factors back in time for the nonsectioned sample trees. These estimated cylindrical form factors, along with the corresponding heights and diameters, were then used to calculate volumes for each nonsectioned sample tree at each desired point in time: Volume = (basal area) (total height)(form factor). Basal area at each point in time was determined from the diameter measurements;

Table 1--Values for a and by by years for the family of regressions[1] for estimating site index for Douglas-fir east of the Cascades in the Pacific Northwest

Breast-high age	Years between decades																			
	0		1		2		3		4		5		6		7		8		9	
	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b
Years																				
10	32.217	3.235	30.319	2.986	38.679	2.778	27.069	2.602	25.550	2.451	24.113	2.319	22.751	2.204	21.457	2.103	20.228	2.012	19.056	1.931
20	17.940	1.858	16.875	1.792	15.585	1.731	14.886	1.676	13.958	1.625	13.069	1.579	12.219	1.535	11.406	1.495	10.627	1.458	9.881	1.423
30	9.168	1.390	8.484	1.359	7.830	1.331	7.204	1.304	6.605	1.278	6.032	1.254	5.483	1.231	4.959	1.209	4.458	1.188	3.979	1.168
40	3.522	1.150	3.085	1.132	2.760	1.114	2.274	1.098	1.896	1.082	1.537	1.067	1.196	1.053	.872	1.039	.565	1.025	.274	1.012
50	0	1	-.260	.988	-.505	.976	-.735	.965	-.951	.954	-1.153	.944	-1.342	.934	-1.518	.924	-1.681	.914	-1.832	.905
60	-1.971	.896	-2.098	.887	-2.214	.879	-2.319	.870	-2.413	.862	-2.496	.854	-2.569	.847	-2.632	.839	-2.685	.832	-2.729	.825
70	-2.764	.818	-2.789	.811	-2.806	.804	-2.814	.798	-2.814	.791	-2.805	.785	-2.789	.779	-2.764	.773	-2.732	.767	-2.693	.761
80	-2.646	.756	-2.593	.750	-2.532	.745	-2.465	.740	-2.391	.734	-2.311	.729	-2.224	.724	-2.132	.719	-2.033	.714	-1.928	.709
90	-1.818	.705	-1.703	.700	-1.582	.695	-1.455	.691	-1.324	.687	-1.187	.682	-1.046	-.961	-.900	.674	-.749	.669	-.594	.665
100	-.434	.661																		

[1]To estimate site index, measure height of the 3 tallest trees per 1/5-acre plot. Determine breast-high age for each of these trees. Select appropriate a and b values above. Substitute values in the equation, Site index - 4.5 feet = a + b (height - 4.5 feet). For example, for a tree 53 years old at breast height and 60 feet in total height, solve the equation, SI - 4.5 = -0.735 + 0.965 (60 - 4.5), for a site index of 57.3. Determine the site index for each of the 3 trees. The highest site index determined is the site index for the 1/5-acre plot.

Source: Cochran (1979a).

Table 2--Values for a and b by years for the family of regressions[1] for estimating site index for white or grand fir east of the Cascades in the Pacific Northwest

Breast-high age	Years between decades																			
	0		1		2		3		4		5		6		7		8		9	
	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b
Years																				
10	53.778	2.353	52.315	2.177	50.808	2.035	49.266	1.917	47.699	1.819	46.112	1.735	44.511	1.663	42.903	1.600	41.290	1.546	39.678	1.497
20	38.069	1.455	36.467	1.416	34.876	1.382	33.296	1.350	31.732	1.322	30.185	1.296	28.656	1.273	27.149	1.251	25.663	1.231	24.201	1.212
30	22.764	1.195	21.353	1.179	19.968	1.164	18.612	1.150	17.283	1.137	15.983	1.125	14.711	1.113	13.470	1.102	12.257	1.092	11.075	1.082
40	9.922	1.073	8.799	1.064	7.706	1.056	6.641	1.048	5.607	1.040	4.601	1.033	3.624	1.026	2.675	1.019	1.754	1.012	.860	1.006
50	0	1.000	-.846	.994	-1.659	.989	-2.447	.983	-3.210	.978	-3.948	.973	-4.662	.968	-5.353	.963	-6.020	.958	-6.665	.954
60	-7.288	.949	-7.889	.945	-8.469	.941	-9.029	.936	-9.569	.932	-10.090	.928	-10.591	.924	-11.074	.920	-11.539	.917	-11.987	.913
70	-12.417	.909	-12.831	.906	-13.228	.902	-13.609	.899	-13.975	.895	-14.326	.892	-14.661	.888	-14.983	.885	-15.290	.882	-15.584	.878
80	-15.863	.875	-16.130	.872	-16.384	.869	-16.625	.866	-16.853	.863	-17.069	.859	-17.273	.856	-17.466	.853	-17.646	.850	-17.815	.847
90	-17.973	.844	-18.119	.842	-18.255	.839	-18.379	.836	-18.493	.833	-18.596	.830	-18.688	.827	-18.770	.824	-18.841	.823	-18.901	.819
100	-18.951	.816																		

[1] To estimate site index, measure total height of up to 5 tallest trees per 1/5-acre plot; determine breast-high age for each. Select appropriate a and b values above. Substitute values in the equation, Site index - 4.5 feet = a + b (height - 4.5 feet). For example, for a tree 53 years old at breast height and 80 feet in total height, solve the equation, Site index - 4.5 feet = -2.447 feet + 0.983 (80 feet - 4.5 feet), for a site index of 76.3 feet. Determine the site index for each sample tree. The highest site index determined is the site index for white or grand fir on the 1/5-acre plot.

Source: Cochran (1979b).

a constant ratio was assumed for diameter outside bark and diameter inside bark.

Different procedures for sectioning were used on the two classes of plots because I wanted to project plots back in time as far as possible where mortality appeared to be negligible for another study. Where significant mortality appeared to have occurred beyond 10 or 20 years in the past, the second sectioning procedure, which was less time consuming, allowed accurate determinations of growth in the recent past. Sections at ground line were also taken on all plots from at least five trees, (two large, two small, and one intermediate) to determine total stand age and to make certain the stand was even aged.

Volume of sample trees on each plot at the time of cutting was related to their basal area by the equation:

$$\text{Log (initial volume)} = c + d\ \text{(log current basal area)}.$$

Basal area increment and volume increment of the sample trees for each period back in time on each plot was also related to their basal area at the time of cutting by the equation:

$$\text{Log (basal area increment)} = c_1 + d_1\ \text{(log current basal area)},$$

and

$$\text{log (volume increment)} = c_2 + d_2\ \text{(log current basal area)}.$$

The coefficients of these three equations, determined separately for each plot, were then used to determine the initial volume of the uncut trees on the plot and the volume increment and basal area increment for these uncut trees for past time periods. Coefficients c_1, c_2, d_1, and d_2 varied, of course, on each plot with each time period. Volumes and increments for the cut trees were added to those calculated for the uncut trees (from the appropriate regressions) to obtain plot totals. Plot totals were converted to values per acre. By subtracting volume increments and basal area increments from initial volumes and basal areas, I projected all plots back to 1960. Plots where all the cut trees were sectioned were projected farther back in time to the point where the equations no longer were good predictors of increment.

Volume and basal area increments as a function of age were plotted for each plot. Age was determined by averaging the breast-high ages of the sample trees. Comparison of the shapes of the curves for plots projected 30 or more years back in time showed that certain periods broke above or below general trends for all plots. The 1915-20, 1930-35, 1950-55, and the 1965-70 periods were lower than the general trend for the majority of the plots scattered throughout eastern Oregon and Washington.[2] These periods were probably unusually dry. Eight plots showed marked and prolonged drops in increment, with later recovery. These plots must have been subject to severe attack by insects or to some other disaster. Even though these plots appeared healthy at the time of sampling, they were not used in determining yields reported here. The 1970-75 period seemed not to be one of climatic extremes,

[2] In an investigation of past diameter growth of ponderosa pine in eastern Oregon and Washington, James W. Barrett, Research Forester, found pronounced dips in diameter growth in either or both 1917 and 1918, generally poor growing periods from 1924 to 1937 and 1948 to 1953, and a pronounced dip in 1968. Data on file at the Silviculture Laboratory, Bend, Oregon.

and crown canopy for the sample plots had completely or almost closed by this time. Therefore, we used increment for this period as the gross periodic annual increment.

Multiple regression methods were used to relate the average plot volume increment for the 1970-75 period (the gross periodic annual volume increment) to the site index, the average breast-high age, and the basal area at the midpoint of this period. Volume and basal area found on the plots at the time of sampling were accepted as net yield and net basal area. Multiple regression methods were used to relate net volume to net basal area, site index, and breast-high age. Gross volume yield was obtained as a cumulative summary of gross periodic annual increment from a breast-high age of 20 years plus the net yield at breast-high age 20 (Dahms 1964, 1975; Curtis 1967).

Gross periodic annual basal area increments were also determined. Plot basal area increments for each species were divided by the plot basal area for that species at the midpoint of the period. These periodic basal area increments per unit of basal area were related to site index and age by multiple regression techniques. The resulting equations were then combined with the net basal area functions to determine gross periodic annual basal area increments. Determining gross basal increments in this way allowed use of two values for white (grand) fir for breast-high ages less than 25 years.

It should be noted that the subjective selection of small plots with complete or nearly complete crown closure but no evidence of recent mortality may produce net basal areas and volumes somewhat higher than are actually attainable on substantial areas. The ratio of net to gross increment may also be overestimated.

Results

A total of 97 plots were sampled; therefore, the sampling objectives were not completely met. Presence of older remnant trees, dense clumps of trees separated by openings, thinning, harvest cutting, and near absence of young stands with closed crown canopies caused difficulty in finding plots that met our criteria, particularly in stands less than 30 years and older than 100. After they were sampled, several plots were discarded from the study because abrupt breaks in the height growth curves for the sectioned sample trees showed severe damage in the past, and it was now impossible to assign a meaningful site index value to these plots. A few plots were discarded because their basal areas were very high and the shape of their height growth curves indicated that density was retarding height growth and there was no way to assign a site index value. Two plots were rejected because the ages at ground line were not within the limits we could accept as "even-aged."

Net basal area and volume.--Twenty-six plots with greater than 90 percent basal area Douglas-fir and 26 additional plots with at least 90 percent basal area white (grand) fir were used to define the net basal area curves for each species. The site indexes for these plots within each 10-year breast-high age class were:

Breast-high age class	Site index (feet): Douglas-fir	Site index (feet): White or grand fir
11-20	104, 110.1, 117.8	--
21-30	59.4, 67.3, 87.7	--
31-40	--	79.3, 94.4, 94.6, 95.3, 96, 102.5
41-50	81, 84.9, 105	74, 90.4
51-60	79, 101.7	64.2, 71.9, 73.5, 83.5
60-70	79, 85, 87, 96.3, 102.4, 105.4	53.1, 65.9, 69.2, 90, 90, 98
71-80	52.7, 69.1, 73.5, 106.4	58.9, 59.6, 63.9, 89, 92.3
81-90	63.1, 65.2, 69, 69.2	74.8, 94.5
91-100	54.3	64.5

Net Douglas-fir basal area (table 3), BA, is:

$$BA = e^{(6.0735 + 7.4887/\log age + 0.22185 \log SI - 64.2213/(\log SI \cdot \log age))}.$$

The standard error and R^2 values are 33.0 ft^2/acre and 0.79.

Net white (grand) fir basal area (table 4), BA_1, is:

$$BA_1 = e^{(6.3216 + 0.1819 \log SI - 0.9365/\log age - 22.4376/(\log SI \cdot \log age))};$$

standard error is 27.7 ft^2/acre and R^2, 0.54.

In the two previous equations and in those that follow, SI is site index, age is breast-high age, logarithms are natural, and the standard errors and R^2 values are for the equations as written, not their logarithmic forms.

Thirty-one plots were used to describe the net volume equation for Douglas-fir and 37 plots for white (grand) fir. Some additional plots which were not quite as pure were used for each species along with those used for obtaining the basal area curves. The additional plots had from 15 to 30 percent basal area of other species besides the

Table 3--Net basal area of Douglas-fir east of the Cascades in Oregon and Washington as a function of age at breast height and site index[1]

Breast-high age	Site index (feet)						
	50	60	70	80	90	100	110
Years	Square feet per acre						
20	53	70	87	105	122	140	157
25	65	84	104	124	143	162	181
30	75	97	118	140	160	181	201
35	84	107	130	153	175	196	217
40	92	117	141	164	187	210	231
45	99	125	150	175	198	221	243
50	106	132	159	184	208	232	254
55	111	139	166	192	217	241	264
60	117	145	173	199	225	249	273
65	122	151	179	206	232	257	281
70	126	156	185	212	239	264	288
75	131	161	190	218	245	270	295
80	135	166	195	224	251	276	301
85	139	170	200	229	267	282	307
90	142	174	205	233	261	287	312
95	146	178	209	238	266	292	318
100	149	182	213	242	270	297	322

[1]Reference age for site index is 50 years at 4.5 feet.

Table 4--Net basal area of white (grand) fir east of the Cascades in Oregon and Washington as a function of age at breast height and site index[1]

Breast-high age	Site index (feet)						
	50	60	70	80	90	100	110
Years	- - - - - - - - - - Square feet per acre - - - - - - - - - -						
20	122	138	151	164	175	185	195
25	143	160	175	188	200	212	222
30	159	178	194	208	221	233	244
35	174	193	210	225	238	251	263
40	186	206	223	239	253	266	278
45	196	217	235	252	266	280	292
50	206	227	246	263	278	291	304
55	214	236	255	272	288	302	315
60	222	244	264	281	297	311	324
65	229	252	272	289	305	320	333
70	236	259	279	297	313	328	341
75	242	265	286	304	320	335	349
80	247	271	292	310	327	342	356
85	252	276	297	316	333	348	362
90	257	282	303	321	338	354	368
95	262	286	308	327	344	359	373
100	266	291	312	331	349	364	379

[1]Reference age for site index is 50 years at 4.5 feet.

one of interest. Additional species were usually mixtures of western larch (*Larix occidentalis* (Nutt.)), Engelmann spruce (*Picea engelmannii* (Parry)), ponderosa pine (*Pinus ponderosa* (Laws.)), western white pine (*Pinus monticola* (Dougl.)), and white or grand fir in the Douglas-fir plots and mixtures of very small amounts of larch and larger amounts of Engelmann spruce plus Douglas-fir in the white or grand fir plots. The additional plots furnished some high site indexes at ages 80 to 120 years for Douglas-fir and provided some additional data at ages below 60 years for both species.

The net volume for Douglas-fir (table 5), V, is:

$$V = e^{(1.507 + 0.4215 \log SI + 1.4052 \log BA - 64.8795/(\log age \cdot \log SI) + 138.8385/(\log age \cdot \log SI \cdot \log BA))}.$$

Standard error and R^2 values are 869.3 ft^3/acre and 0.97.

White or grand fir net volume (table 6), V_1, is:

$$V_1 = e^{(13.5218 - 33.5588/(\log SI \cdot \log BA_1) - 317.4388/(\log age \cdot \log SI \cdot \log BA_1))};$$

standard error is 1,005.6 ft^3/acre and R^2, 0.90.

Gross periodic annual volume increments for Douglas-fir were determined from the same 26 plots used in finding the equation for net basal area plus one additional plot that contained 20 percent white (grand) fir. This plot was 125 years old at the time of sampling and had a site index of 97.4. More mixed plots were not used because the larch and pine in these Douglas-fir plots were growing at different rates than the Douglas-fir. In young stands, larch and pine will outgrow

Table 5--Net volume of Douglas-fir east of the Cascades in Oregon and Washington as a function of age at breast height and site index[1]

Breast-high age	Site index (feet)						
	50	60	70	80	90	100	110
Years	Cubic feet per acre						
20	481	717	1,014	1,371	1,787	2,262	2,793
25	669	1,010	1,433	1,937	2,518	3,175	3,905
30	865	1,311	1,860	2,507	3,248	4,081	5,001
35	1,064	1,614	2,284	3,070	3,965	4,964	6,063
40	1,263	1,914	2,701	3,619	4,660	5,817	7,085
45	1,460	2,208	3,109	4,153	5,332	6,639	8,065
50	1,654	2,496	3,505	4,670	5,981	7,428	9,004
55	1,844	2,778	3,890	5,170	6,606	8,187	9,904
60	2,030	3,051	4,264	5,654	7,208	8,916	10,767
65	2,213	3,318	4,626	6,121	7,790	9,618	11,596
70	2,391	3,578	4,978	6,574	8,350	10,294	12,392
75	2,565	3,830	5,319	7,011	8,892	10,945	13,158
80	2,735	4,076	5,650	7,436	9,415	11,573	13,897
85	2,901	4,316	5,972	7,847	9,922	12,180	14,609
90	3,064	4,550	6,285	8,245	10,412	12,767	15,296
95	3,222	4,777	6,589	8,633	10,888	13,336	15,961
100	3,378	5,000	6,885	9,009	11,349	13,886	16,605

[1]Reference age for site index is 50 years at 4.5 feet.

Table 6--Net volume of white (grand) fir east of the Cascades in Oregon and Washington as a function of age at breast height and site index[1]

Breast-high age	Site index (feet)						
	50	60	70	80	90	100	110
Years	Cubic feet per acre						
20	446	736	1,073	1,444	1,838	2,249	2,671
25	821	1,284	1,800	2,350	2,921	3,504	4,093
30	1,244	1,879	2,567	3,285	4,018	4,757	5,495
35	1,689	2,489	3,337	4,209	5,089	5,968	6,839
40	2,142	3,095	4,091	5,104	6,118	7,122	8,111
45	2,593	3,690	4,823	5,964	7,098	8,216	9,310
50	3,036	4,268	5,527	6,787	8,031	9,250	10,440
55	3,470	4,827	6,203	7,571	8,916	10,228	11,505
60	3,892	5,366	6,851	8,320	9,757	11,155	12,511
65	4,302	5,886	7,473	9,034	10,556	12,033	13,462
70	4,699	6,387	8,068	9,716	11,318	12,867	14,363
75	5,084	6,870	8,640	10,368	12,044	13,661	15,219
80	5,458	7,335	9,188	10,993	12,737	14,417	16,033
85	5,819	7,784	9,716	11,591	13,400	15,139	16,810
90	6,170	8,217	10,223	12,166	14,035	15,830	17,551
95	6,509	8,635	10,712	12,718	14,645	16,492	18,260
100	6,839	9,039	11,183	13,249	15,230	17,126	18,940

[1]Reference age for site index is 50 years at 4.5 feet.

Douglas-fir; but at ages beyond 50 or 60 years, Douglas-fir outgrows the larch and pine. The same 37 plots used in determining the net volume equations for white (grand) fir were also used in determining gross periodic annual increments. The mixed plots within these samples contained mostly Douglas-fir and small amounts of Engelmann spruce in addition to the white (grand) fir. Annual gross volume growth per unit basal area[3] for these species on these plots was not significantly different from annual gross volume growth per unit basal area for white fir.

Gross periodic annual volume increment (fig. 1), dV, for Douglas-fir is:

$$dV = e^{(-8.2577 + 1.7487 \log SI + 1.3292 \log BA + 0.1699 \log age \cdot \log SI - 0.0484 \log age \cdot \log SI \cdot \log BA)}.$$

Standard error and R^2 values are 21.1 ft^3/acre per year and 0.92.

Gross periodic annual volume increment for white or grand fir (fig. 2), dV_1, is:

$$dV_1 = e^{(0.7391 + 0.3847 \log BA_1 + 0.2044 \log SI \cdot \log BA_1 - 0.02541 \log age \cdot \log SI \cdot \log BA_1)}.$$

Standard error and R^2 values are 25.3 ft^3/acre per year and 0.80.

[3] Annual gross volume growth per unit basal area here is the average volume growth for a given species on a plot during the 1970-75 period divided by the midpoint basal area of the period for that species.

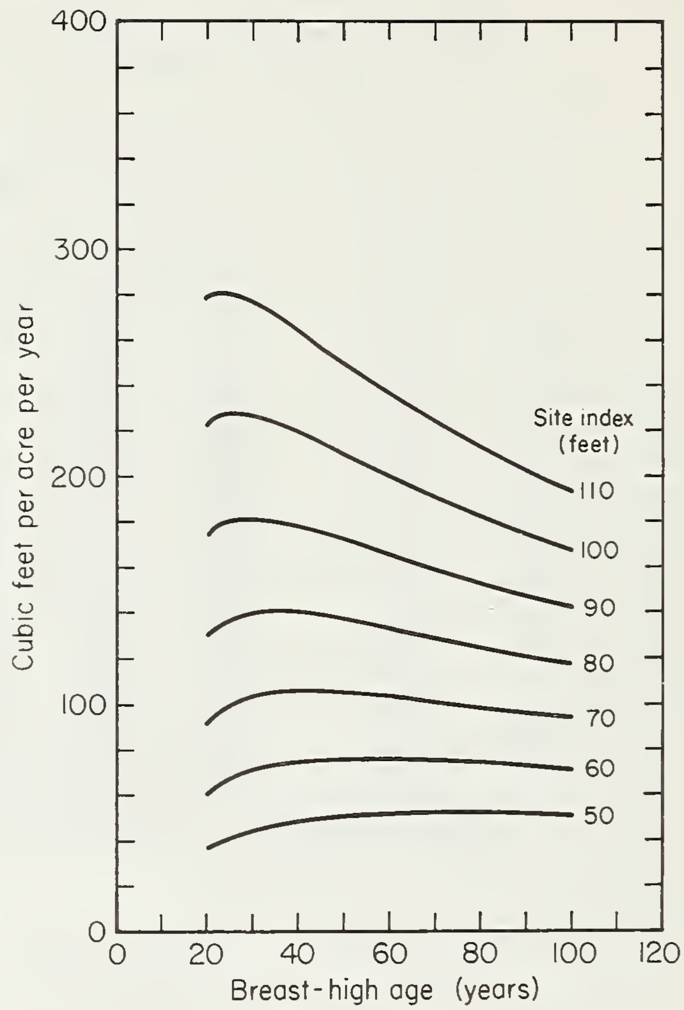
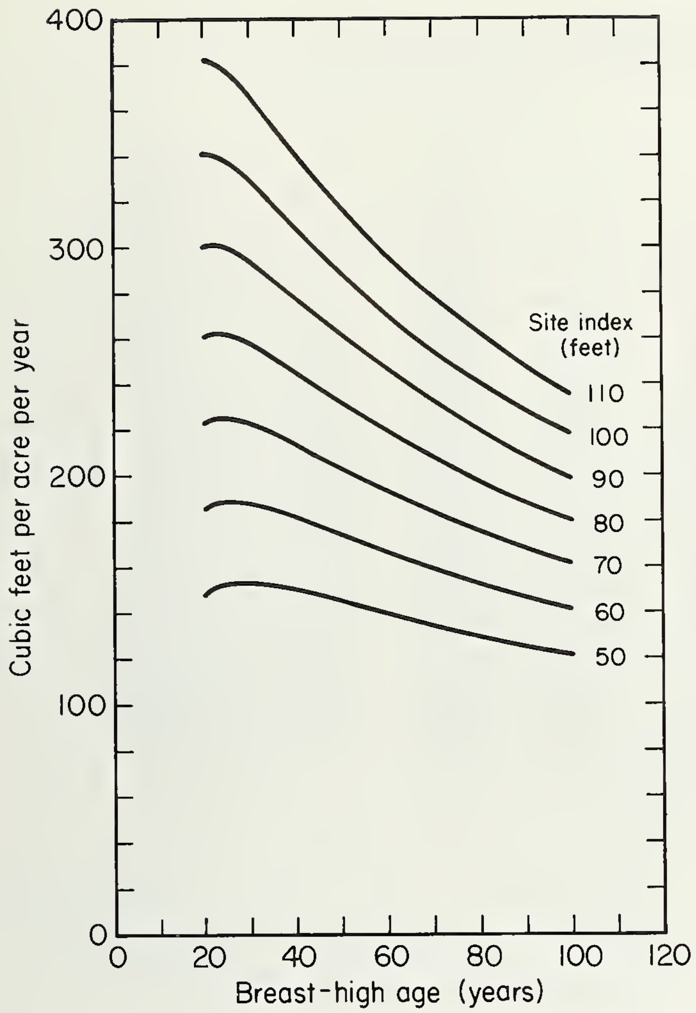


Figure 1.--Gross periodic annual volume increment for Douglas-fir east of the Cascades in Oregon and Washington.

The gross volume yields determined from these increment equations and the net yields at breast-high age 20 years are given in tables 7 and 8.

Gross periodic annual basal area increments per unit basal area were determined from 43 plots for Douglas-fir and 46 plots for white (grand) fir. These plots include those used in determining the gross periodic annual volume increments plus additional plots where at least 40 percent of the basal area was of the species concerned. For Douglas-fir gross periodic annual basal area increment per unit of basal area is:



$$d(BA)/BA = e^{(10.0227 - 0.5686 \log SI}$$
$$- 2.7624 \log age$$
$$- 28.4193/(\log SI \cdot \log age)$$
$$+ 0.00668 (\log age)^3 \cdot \log SI$$
$$- 0.01102 (\log SI)^2 \cdot \log age)$$

Standard error and R^2 values are 0.0068 and 0.92.

For white (grand) fir,

$$d(BA_1)/BA_1 = e^{(1.4743}$$
$$- 1.5379 \log age$$
$$+ 0.5212 \log age/\log SI$$
$$+ 0.00000001 (\log age)^{10} \cdot \log SI)$$

Figure 2.--Gross periodic annual volume increment for white (grand) fir east of the Cascades in Oregon and Washington.

Table 7--Gross volume yield for Douglas-fir east of the Cascades in Oregon and Washington[1]

Breast-high age	Site index						
	50	60	70	80	90	100	110
Years	Cubic feet per acre						
25	679	1,042	1,497	2,042	2,675	3,393	4,193
30	897	1,390	2,004	2,736	3,579	4,530	5,585
35	1,128	1,753	2,525	3,437	4,483	5,656	6,951
40	1,369	2,125	3,051	4,138	5,378	6,762	8,283
45	1,616	2,501	3,578	4,835	6,261	7,846	9,580
50	1,868	2,881	4,105	5,525	7,129	8,904	10,841
55	2,123	3,261	4,628	6,206	7,980	9,938	12,066
60	2,380	3,641	5,146	6,877	8,816	10,947	13,257
65	2,638	4,019	5,660	7,538	9,634	11,932	14,417
70	2,897	4,396	6,168	8,189	10,437	12,895	15,545
75	3,156	4,770	6,670	8,829	11,224	13,835	16,645
80	3,414	5,142	7,167	9,460	11,996	14,755	17,717
85	3,672	5,511	7,657	10,080	12,754	15,654	18,763
90	3,930	5,877	8,142	10,691	13,497	16,535	19,785
95	4,186	6,240	8,620	11,293	14,227	17,397	20,783
100	4,442	6,599	9,093	11,885	14,944	18,242	21,759

[1]Reference age for site index is 50 years at 4.5 feet.

Table 8--Gross volume yield for white (grand) fir east of the Cascades in Oregon and Washington[1]

Breast-high age	Site index (feet)						
	50	60	70	80	90	100	110
Years	Cubic feet per acre						
25	1,202	1,673	2,195	2,754	3,340	3,947	4,567
30	1,967	2,613	3,312	4,052	4,821	5,613	6,420
35	2,730	3,543	4,413	5,323	6,266	7,231	8,214
40	3,484	4,458	5,489	6,563	7,668	8,797	9,945
45	4,227	5,355	6,540	7,768	9,028	10,312	11,614
50	4,957	6,233	7,565	8,939	10,345	11,775	13,223
55	5,674	7,092	8,564	10,078	11,623	13,191	14,777
60	6,378	7,931	9,538	11,185	12,862	14,562	16,278
65	7,069	8,752	10,487	12,261	14,065	15,890	17,731
70	7,746	9,555	11,414	13,310	15,234	17,178	19,137
75	8,412	10,342	12,319	14,332	16,371	18,429	20,502
80	9,065	11,111	13,203	15,328	17,478	19,646	21,826
85	9,706	11,866	14,068	16,301	18,557	20,830	23,113
90	10,337	12,605	14,914	17,251	19,610	21,983	24,366
95	10,956	13,331	15,742	18,180	20,637	23,107	25,586
100	11,566	14,043	16,554	19,089	21,641	24,204	26,775

[1]Reference age for site index is 50 years at 4.5 feet.

Standard error and R^2 values are 0.004 and 0.96. Multiplying these functions by the appropriate expression for net basal area produces the gross periodic annual basal area increments (table 9 and 10).

Table 9--Gross periodic annual basal area increment for Douglas-fir east of the Cascades in Oregon and Washington as a function of age at breast height and site index[1]

Breast-high age	Site index (feet)						
	50	60	70	80	90	100	110
Years	Square feet per acre per year						
15	3.8	5.2	6.6	7.9	9.1	10.3	11.4
20	3.5	4.6	5.7	6.7	7.6	8.5	9.3
25	3.1	4.1	4.9	5.7	6.4	7.1	7.7
30	2.8	3.6	4.3	4.9	5.5	6.1	6.6
35	2.6	3.2	3.8	4.4	4.9	5.4	5.8
40	2.3	2.9	3.5	4.0	4.4	4.8	5.2
45	2.2	2.7	3.2	3.6	4.0	4.4	4.7
50	2.0	2.5	2.9	3.3	3.7	4.0	4.3
55	1.9	2.3	2.7	3.1	3.4	3.8	4.0
60	1.8	2.2	2.6	2.9	3.2	3.5	3.8
65	1.7	2.1	2.5	2.8	3.1	3.3	3.6
70	1.6	2.0	2.3	2.6	2.9	3.2	3.4
75	1.5	1.9	2.2	2.5	2.8	3.0	3.3
80	1.5	1.8	2.2	2.4	2.7	2.9	3.2
85	1.4	1.8	2.1	2.4	2.6	2.8	3.1
90	1.4	1.7	2.0	2.3	2.5	2.8	3.0
95	1.4	1.7	2.0	2.2	2.5	2.7	2.9
100	1.3	1.6	1.9	2.2	2.4	2.6	2.8

[1]Reference age for site index is 50 years at 4.5 feet.

Table 10--Gross periodic annual basal area increment for white (grand) fir east of the Cascades in Oregon and Washington as a function of age at breast height and site index[1]

Breast-high age	Site index (feet)						
	50	60	70	80	90	100	110
Years	Square feet per acre per year						
15	9.4	10.5	11.5	12.4	13.2	13.9	14.6
20	8.0	8.8	9.5	10.2	10.8	11.3	11.9
25	6.8	7.5	8.1	8.6	9.0	9.5	9.9
30	5.9	6.5	6.9	7.4	7.7	8.1	8.4
35	5.2	5.7	6.1	6.4	6.7	7.0	7.3
40	4.6	5.0	5.4	5.7	6.0	6.2	6.4
45	4.2	4.5	4.8	5.1	5.3	5.5	5.7
50	3.8	4.1	4.4	4.6	4.8	5.0	5.2
55	3.5	3.8	4.0	4.2	4.4	4.6	4.7
60	3.2	3.5	3.7	3.9	4.1	4.2	4.4
65	3.0	3.3	3.5	3.6	3.8	3.9	4.1
70	2.8	3.1	3.2	3.4	3.5	3.7	3.8
75	2.7	2.9	3.0	3.2	3.3	3.5	3.6
80	2.5	2.7	2.9	3.0	3.2	3.3	3.4
85	2.4	2.6	2.7	2.9	3.0	3.1	3.2
90	2.3	2.5	2.6	2.7	2.9	3.0	3.1
95	2.2	2.4	2.5	2.6	2.7	2.8	2.9
100	2.1	2.3	2.4	2.5	2.6	2.7	2.8

[1]Reference age for site index is 50 years at 4.5 feet.

Reasonableness of Results

NET BASAL AREA

The net basal area equations did a poorer job accounting for variability than did the equations for net volume or periodic annual increment. Net volume and periodic annual increment are a function of basal area as well as site index and age. Therefore, the net basal area functions must be good predictors if the net volume and periodic annual increment functions are to be reliable.

Douglas-fir.--Comparison of the basal area curves given here with preliminary results for the west side from a yield study of Douglas-fir by the Pacific Northwest Forest and Range Experiment Station and Weyerhaeuser Company show close to the same results for site indexes 75 to 90 feet.[4] For site index 110 feet, my curves are 15 percent higher for breast-high ages of 20 to 100.[5]

White (grand) fir.--The low R^2 value for my white fir basal area curves reflects high variability of the data, not the unreasonableness of shape. These white fir curves are generally shaped like my Douglas-fir curves and the curves for second-growth mixed conifer stands in California (Dunning and Reineke 1933).

[4]The west-side index curves have a reference age of 50 years at breast height, but the heights are the average of a fixed number of largest diameter trees per acre. Therefore, they are not strictly comparable to my curves (table 1).

[5]Personal communication with Robert O. Curtis, Pacific Northwest Forest and Range Experiment Station, Forestry Sciences Laboratory, Olympia, Washington.

As a partial check on the accuracy of the white fir basal area curves, a technician prism-cruised seven small, even-aged stands of white fir picked from aerial photos on the Deschutes National Forest in central Oregon. A 10.255 factor prism was used. Plots were systematically located on a 140-foot grid. The two tallest trees counted at each prism point were bored at breast height, and their heights were measured with a clinometer. Site index for the prism point was the highest of the determinations of the two trees. Basal areas and site indexes were averaged for all the points in each stand. The highest deviation between the average basal area and predicted values was 12 ft^2/acre (table 11).

GROSS VOLUME YIELD

Reliability of gross volume yields can be checked by comparing them with net yields (table 12). For Douglas-fir at age 80, net volume yield ranges from 80 percent of gross volume yield for site index 50 to 78.4 percent of the gross yield for site index 110. At age 100, the net volume yield is 76 percent of gross yeild for all site indexes; and if the yields are projected to 120 years, net yield ranges from 72.7 percent of gross for site index 50 to 74 percent for site index 110. This compares closely with results of Curtis (1967) and Staebler (1955). Staebler (1955) found that net volume yields for site III, west-side Douglas-fir represented 79 to 73 percent of gross volume yield at ages 80 to 120 years. Similarly, net volume yield of ponderosa pine represents 79 to 74 percent of gross yeild at ages 80 to 120 years for site index 80 (Meyer 1938). Net volume yield from the British Columbia yield table (British Columbia Forest Service 1947) for lodgepole pine represents 68 to 63 percent of gross volume yield at ages of 80 to 120 years. Dahms (1975) found that net volume yield

Table 11--Comparison of actual and predicted basal area values for 9 small, undamaged, even-aged white (grand) fir stands

Location	Approximate size	Number of plots	Age	Site index		Basal area		
				Range	Average	Range	Average	Predicted
	Acres		Years	Feet		Square feet per acre		
T. 19 S., R. 10 E., SE¼ sec. 6	30	19	79	54-73	62	133-420	262	274
T. 19 S., R. 10 E., NW¼ sec. 2	20	15	46	50-73	60	123-313	225	219
T. 19 S., R. 10 E., S½ sec. 20	10	10	93	56-80	67	205-405	302	300
T. 20 S., R. 7 E., SE¼ sec. 13	4	6	101	67-79	72	205-338	314	317
T. 14 S., R. 10 E., NE¼ sec. 10	5	6	70	79-99	90	297-359	309	313
T. 20 S., R. 7 E., NE¼ sec. 24	12	10	96	65-78	71	227-338	308	311
T. 19 S., R. 10 E., SW¼ sec. 6	20	15	85	64-83	73	246-395	315	303

Table 12--Net volume yield of white (grand) fir and Douglas-fir expressed as a percent of gross volume yield[1]

Breast-high age	Site index (feet)						
	50	60	70	80	90	100	110
Years	Percent						
	WHITE (GRAND) FIR						
80	60.2	66.0	69.6	71.7	72.9	73.4	73.5
85	60.0	65.6	69.1	71.1	72.2	72.7	72.7
90	59.7	65.2	68.5	70.5	71.6	72.0	72.0
95	59.4	64.8	68.0	70.0	71.0	71.4	71.4
100	59.1	64.4	67.6	69.4	70.4	70.8	70.7
	DOUGLAS-FIR						
80	80.1	79.3	78.8	78.6	78.5	78.4	78.4
85	79.0	78.3	78.0	77.8	77.8	77.8	77.9
90	78.0	77.4	77.2	77.1	77.1	77.2	77.3
95	77.0	76.6	76.4	76.4	76.5	76.7	76.8
100	76.0	75.8	75.7	75.8	75.9	76.1	76.3

[1]Reference age for site index is 50 years at 4.5 feet.

represented 63 to 73 percent of gross yield at age 120 years for site indexes ranging from 60 to 110.

Net volume yields for white (grand) fir are a smaller percentage of the gross volume yield than for Douglas-fir. At age 80, net yield ranged from 60 percent of gross yield for site index 50 to 73.7 percent for site index 110. At age 100, the percentages ranged from 59 for site index 50 to 71 for site index 110. If yields for white (grand) fir are projected to 120 years, net volume yields range from 58 to 68 percent of the gross volume yield for site index 50 to 110. These percentages are less certain than those for Douglas-fir because no white (grand) fir plots were sampled in the 20- to 30-year age class, and the starting point for accumulating gross yield was 20-year-breast-high age.

GROSS PERIODIC ANNUAL BASAL AREA GROWTH

Curtis (1967) presents gross periodic annual basal area growth of west-side Douglas-fir for site indexes of 80 to 140 feet (see footnote 4). For breast-high ages beyond 25 years, my curves are 0.3 to 0.4 ft^2/acre per year lower at site index 80 feet and 0.1 to 0.2 ft^2/acre per year higher at site index 110 feet. Under 15-year-breast-high age, the values presented by Curtis are higher than shown by my curves, but I had only one plot below this age.

I could locate no published values for gross basal area growth of white fir. The gross periodic annual basal area growth curves for white (grand) fir are higher than those for Douglas-fir as expected, except for site index 110 feet beyond the 95-year-breast-high age. No data were used in the construction of the white fir curves at these high sites and ages, however, and no data were used from plots below 20 years of age. Therefore, these curves above 80 years and for high sites and below 20 years are questionable.

Application

These results provide first approximations of potential production in pure or nearly pure, even-aged stands which are relatively uniform and in which no stagnation or serious injury occurs. Currently, many young stands do undergo periods when height growth is suppressed because of scattered remnant overstory trees, competing vegetation, and high densities. Perhaps these factors can be controlled by management practices in the future, but they make application of these results uncertain in many existing stands. Future management practices may moderate but not eliminate injuries to stands by insects, diseases, and storms. These results can be helpful in assessing the loss of productivity caused by injury. These results can be used to estimate potential production in existing pure or nearly pure stands where:

1. The stand is one storied, there are no older remnants from earlier stands, and the stand can be classified as even aged.
2. There are no visible signs of insect or disease attack that would reduce growth.
3. There are no narrow ring groups of 5 or more years which indicate suppression.
4. There are no remnants of excessive understory vegetation or suppression mortality that indicate severe competition early in the life of the stand.
5. The crown canopy is closed or very nearly closed.

For sampling applicable stands, site index should be determine by boring and measuring the heights of three to five of the tallest trees on a number of 1/5-acre plots. The highest site index value determined from these three to five trees is the site index for the plot. The average site index for all the plots sampled is the site index for the area of concern. Several more trees in the intermediate and codominant height classes should be bored on each plot, and the average age of all the bored trees should be used as the breast-high age. The average site index and breast-high age should then be used with the existing measured basal area in the appropriate equations to determine potential volume and basal area growth.

For applicable stands that are mixtures of white (grand) and Douglas-fir, site index should be determined for both species on each plot if both species have dominant trees. The highest site index determined should be recorded for the plot regardless of species. For stands that have 80 percent or more of their basal area in a single species, the stands can be considered as either Douglas-fir or white (grand) fir in the application of the equations and volume growth. For mixed stands of Douglas-fir and white (grand) fir that have more than 20 percent of their basal area in the minority species, I suggest solving the Douglas-fir and white (grand) fir equations separately with the existing basal areas and then adding the results together to determine growth rates.

The plots in this study did not include nonproductive areas, such as roads, streams, rock outcrops, and talus slopes. Therefore, land managers must make adjustments downward in applying these results to large areas. There is no simple way to make this adjustment. Bruce (1977) suggests that the areas of application "be surveyed with mappable nonproductive areas excluded, and an allowance determined for areas too small to map."

Literature Cited

British Columbia Forest Service.
1947. Yield tables. 7 p.

Bruce, David.
1977. Yield differences between research plots and managed forests. J. For. 75(1):14-17, illus.

Cochran, P. H.
1979a. Site index and height growth curves for managed, even-aged stands of Douglas-fir east of the Cascades in Oregon and Washington. USDA For. Serv. Res. Pap. PNW-251, 16 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Cochran, P.H.
1979b. Site index and height growth curves for managed, even-aged stands of white or grand fir east of the Cascades in Oregon and Washington. USDA For. Serv. Res. Pap. PNW-252, 13 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Curtis, Robert O.
1967. A method of estimating gross yield of Douglas-fir. For. Sci. Monogr. 13, 24 p., illus.

Dahms, Walter G.
1964. Gross and net yield tables for lodgepole pine. USDA For. Serv. Res. Pap. PNW-8, 14 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Dahms, Walter G.
1975. Gross yield of central Oregon lodgepole pine. *In* Management of lodgepole pine ecosystems of symposium proceedings, 208-232 p., illus. David M. Baumgartner, ed. Wash. State Univ. Coop. Ext. Serv., Pullman.

Dunning, Duncan, and L. H. Reineke.
1933. Preliminary yield tables for second-growth stands in the California pine region. U.S. Dep. Agric. Tech. Bull. 354, 23 p. Washington, D.C.

Meyer, Walter H.
1938. Yield of even-aged stands of ponderosa pine. U.S. Dep. Agric. Tech. Bull. 630, 59 p., illus. Washington, D.C.

Staebler, George R.
1955. Gross yield and mortality tables for fully stocked stands of Douglas-fir. USDA For. Serv. Pac. Northwest For. and Range Exp. Stn. Res. Pap. 14, 20 p., illus. Portland, Oreg.

Zobel, Donald B.
1973. Local variation in integrating *Abies grandis-Abies concolor* populations in the central Oregon Cascades: Needle morphology and periderm color. Bot. Gaz. 134(3):209-220.

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Cochran, P. H.
1979. Gross yields for even-aged stands of Douglas-fir and white or grand fir east of the Cascades in Oregon and Washington. USDA For. Serv. Res. Pap. PNW-263, 17 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Equations and tables for predicting net and gross yields for Douglas-fir and white (grand) fir in even-aged stands east of the Cascade Range in Oregon and Washington are presented. Data were collected in stands where height growth apparently was never suppressed by competing understory vegetation, high density, or top damage once the heights of the dominants became greater than 4.5 feet.

KEYWORDS: Yield tables, yield table construction, increment (gross), increment (net), stem analysis, measurement systems, even-aged stands, Douglas-fir, *Pseudotsuga menziesii*, white fir, *Abies concolor*, grand fir, *Abies grandis*.