Old-Growth Douglas-Fir and Western Hemlock: A 36-Year Record of Growth and Mortality

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*ABSTRACT. Growth and mortality were measured at 6-year intervals in a 1,180-acre old-growth stand in southwestern Washington. Principal tree species were Douglas-fir (*Pseudotsuga menziesii*), western hemlock (*Tsuga heterophylla*), Pacific silver fir (*Abies amabilis*), western redcedar (*Thuja plicata*), and western white pine (*Pinus monticola*). They composed 59, 27, 6, 6, and 1%, respectively, of the total cubic volume (13,290 ft^3) in 1947. Gross volume growth averaged 94 ft^3 per acre per year, and mortality averaged 86 ft^3 per acre per year. Net growth was therefore minimal, and total stand volume remained nearly constant for 36 years. Douglas-fir, which accounted for only one-third of the gross growth and nearly one-half of the mortality, is losing dominance to western hemlock, which provided nearly one-half the gross growth and only 28% of the mortality. Pacific silver fir increased in importance in the lower canopy and composed 60% of the ingrowth. Thus, although net gain in timber volume was nil, substantial changes occurred in stand characteristics during the 1947–1983 period.*

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Most of the old-growth Douglas-fir and western hemlock have been logged on private and industrial holdings in the Pacific Northwest; the remaining tracts, primarily on public lands, are therefore receiving increased attention from users and managers of forest resources. Concerns about esthetics, dependent wildlife species, gene pools, and long-term productivity have been voiced in association with the "old-growth" issue. Resource managers are faced with decisions about the fate of old-growth stands and the future role of old-growth in long-term plans for management of the forests. Information on what is happening (stand dynamics) in old-growth stands can be useful background for such decisions.

Thanks to an earlier generation of foresters, we now have a relatively long-term record of growth and mortality in a 450-year-old, undisturbed stand of Douglas-fir, western hemlock, and associated species in western Washington (Figure 1). Summaries of the first 6 and 12 years of measurement in this stand were reported by Steele and Worthington (1955) and King (1961). This paper describes growth and mortality trends among species in a 1,180-acre stand for the 36-year period 1947–1983.

THE STAND

The Thornton T. Munger Research Natural Area (RNA) is within the Wind River Experimental Forest on the Gifford Pinchot National Forest, near Carson, Washington. The 1,180-ac tract lies on the lower eastern and southeastern slopes of Trout Creek Hill, an extinct shield volcano in the Cascade Range in southwestern Washington. Topography is gentle; the soils are well-drained shotty loams and sandy loams of the Stabler series.

The RNA has cool, wet winters and warm, periodically dry summers. Precipitation averages 90 to 100 in. per year, less than 10% of which falls in summer; winter precipitation is often snow, which accumulates in a modest pack lasting several months. Mean annual temperature is 48°F.

Vegetation is intermediate between the *Tsuga heterophylla* and *Abies amabilis* Zones (Franklin and Dyrness 1973). Overstory trees are Douglas-fir, western hemlock, Pacific silver fir, grand fir (*A. grandis*), noble fir (*A. procera*), western redcedar, and western white pine. The understory is composed mostly of Pacific yew (*Taxus brevifolia*), vine maple (*Acer circinatum*), and Pacific dogwood (*Cornus nutallii*). Ground vegetation includes

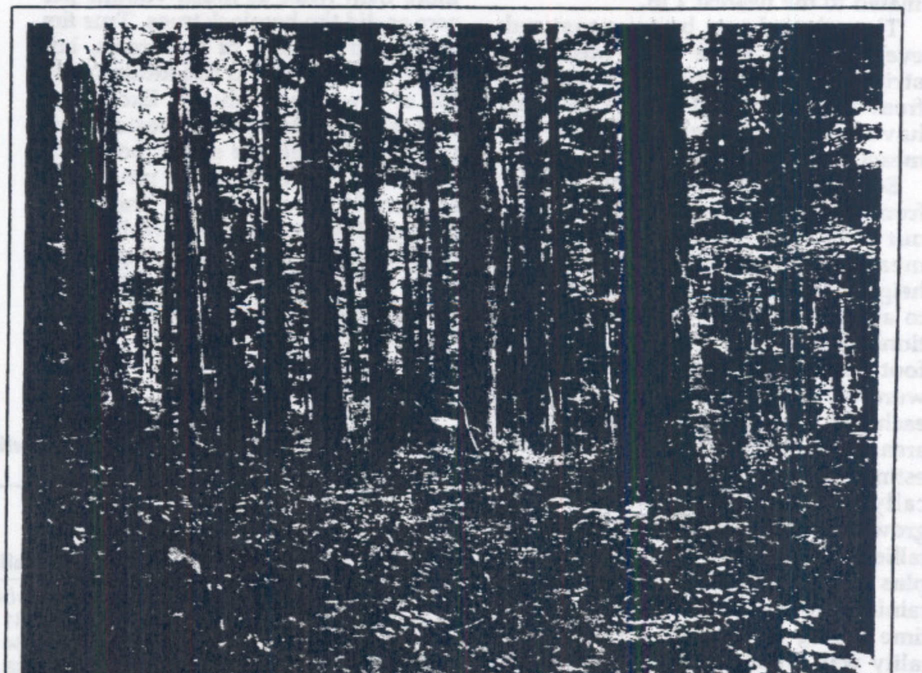

Fig. 1. General view of Douglas-fir and western hemlock in Thornton T. Munger Research Natural Area near Carson, Washington.

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salal (*Gaultheria shallon*), Oregon-grape (*Berberis nervosa*), vanilla-leaf (*Achlys triphylla*), beargrass (*Xerophyllum tenax*), and red whortleberry (*Vaccinium parvifolium*). Douglas-firs in the RNA are 230-460 years old, based on ring counts on stumps in adjacent clearcuts (Franklin and Waring 1979), suggesting that the stand originated after a major disturbance more than 450 years ago. Douglas-fir site class varies from Site III to Site IV (McArdle et al. 1961).

PROCEDURES

Inventory and gross growth data were gathered on 50 concentric plots, 1/20 ac and 1/5 ac in size. Plots were spaced systematically throughout the area at a rate of approximately two per 40 ac. Trees 2.5 to 9.5 in. dbh were tagged and tallied on the 1/20-ac plots, and trees exceeding 9.5 in. dbh were tagged and measured on the 1/5-ac plots. Sampling intensity was about 1% for the larger trees and 0.25% for the smaller trees. Diameters of all trees on these plots were measured by diameter tape to the nearest 0.1 in.; heights of 6 or more trees per plot were measured to the nearest foot by Abney level and chain. Mortality data were collected on continuous cruise strips, 2 chains wide, spaced 20 chains apart. Diameters of trees that died since the last measurement were estimated to the nearest 2 in.

The plots have been measured every 6 years since 1947. Mortality strips were checked every 2 years from 1947–1959, but since 1959 they have been evaluated at the 6-year measurement intervals.

Equations for estimating height from diameter were developed from our data for each tree species. The measured diameter and estimated height of each tree were then applied to appropriate regional volume equations (Browne 1962) to obtain cubic-foot volume per tree. These values were then summed for all trees on each plot to provide volume per unit area. Inventory and gross growth are estimated from data collected periodically on the circular plots. Gross growth includes increment on all trees tallied at the previous measurement plus ingrowth; i.e., volume of trees attaining measurable size for the first time during the growth period. Mortality was calculated from the cruise strips and was subtracted from gross growth to provide estimates of net growth. Board-foot volume (Scribner, 16-ft logs) and volume growth were estimated from ratios calculated from past measurements of cubic- and board-foot volumes in the study plots.

Table 1. Inventory of old-growth stand in Thornton T. Munger Research Natural Area in 1947 (per-acre basis).[1]

Species	Trees	Dq[2]	Volume: Cubic	Volume: Scribner[3]
	Number	*Inches*	*Cunits*[4]	*mbf*[5]
Douglas-fir	24	37	78.3	53.2
Western hemlock	77	14	36.4	21.5
True firs[6]	43	9	8.4	3.8
Western redcedar	5	26	7.8	5.5
Western white pine	1	26	1.4	9.1
Miscellaneous	25	5	0.6	—
Total or average	175	18	132.9	93.1

[1] Includes all stems 2.5 in. dbh and larger.
[2] Quadratic mean diameter.
[3] Sixteen-foot logs.
[4] A cunit is equal to 100 ft^3.
[5] Thousand board feet.
[6] Grand, noble, and Pacific silver firs combined.

RESULTS

The Stand in 1947

The initial inventory showed an average of 175 trees per acre, with estimated volumes of 13,290 ft^3 or 93,000 bd ft (Table 1). Minor discrepancies between these data and earlier reports (Steele and Worthington 1955, King 1961) may be attributed to revised height-diameter relationships and improved volume equations.

Douglas-fir and western hemlock constituted 80–90% of the stand volume in 1947 (Table 1). There were three times as many hemlock trees as Douglas-fir trees, but the latter were substantially larger and contributed more than twice as much volume per acre as did the hemlock trees. True firs accounted for 25% of the stems, but these were small and constituted only 6% of the stand volume. Except for two swampy plots where western redcedar dominated the stand, both redcedar and western white pine were scattered throughout the tract. Although few in number, individual trees of these species were large, and they contributed sizably to stand volume (7% of cubic volume; 16% of board-foot volume).

Growth and Mortality (1947 to 1983)

Gross growth during the 36-year period was nearly 3,400 ft^3 per acre, representing an average annual increment of 94 ft^3 per acre (Table 2). Estimated Scribner gross volume growth was more than 20,000 bd ft or about 565 bd ft/ac/yr. Gross growth varied considerably by period, however (Figure 2). During the 1947–1953 period, gross increment was twice that of the 1965–1971 period. Western hemlock accounted for nearly 50% of gross volume growth, Douglas-fir contributed another 34%, and true firs provided two-thirds of the remaining 16%.

Mortality was an important process in this stand (Table 2, Figure 2). About 3,100 ft^3/ac were lost during the 36-yr period, or 86 ft^3/ac/yr. Equivalent Scribner volume of the mortality was 19,360 bd ft/ac, or 538 bd ft/ac/yr. Mortality also varied by period; losses during the 1947–1953 period averaged 650 bd ft/ac/yr and were higher than losses in other periods. During the entire 36-yr period, Douglas-fir accounted for about 50% of the loss, western hemlock for 28%. Western white pine was a minor component of the stand, but it contributed dispro-

Table 2. Gross growth, mortality, and net growth per acre (1947–83) by species, Thornton T. Munger Research Natural Area.

Species	Gross growth	Mortality	Net growth	Conversion ratio[1]: Gross growth	Conversion ratio[1]: Mortality
	Cubic-foot volume (total stem)				
Douglas-fir	1,138	1,531	−393	6.8	6.5
Western hemlock	1,670	854	+816	5.9	6.2
True firs[2]	385	238	+147	4.5	4.7
Western redcedar	137	80	+57	7.0	6.5
Western white pine	10	381	−371	7.0	6.5
Miscellaneous	39	18	+21	—	—
Total	3,379	3,102	+277		
Per annum	94	86	+8		

[1] Estimated board feet (16-ft logs) per ft^3.
[2] Grand, noble, and Pacific silver firs combined.

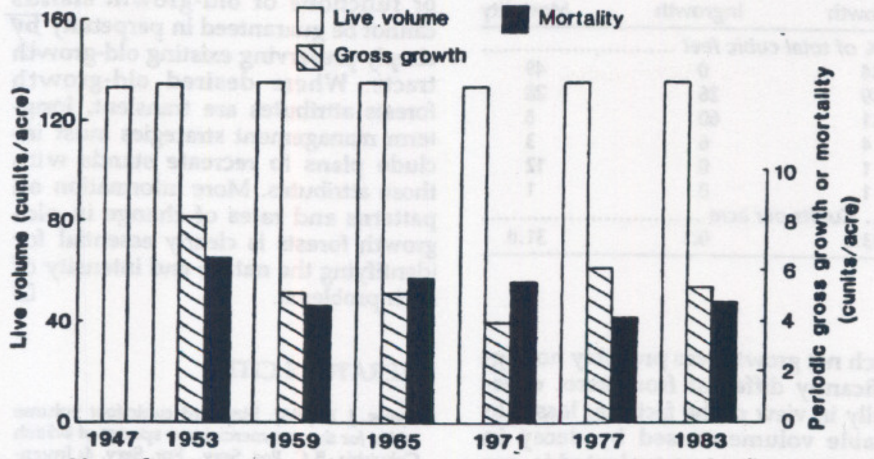

Fig. 2. Live volume, gross growth, and mortality in old-growth Douglas-fir—western hemlock stand in Thornton T. Munger Research Natural Area (1947–1983).

portionately to mortality because most of the western white pine died.

Causes of mortality varied by both species and period. In the early 1950s, Douglas-fir bark beetles (*Dendroctonus pseudotsugae*) were the principal cause of Douglas-fir mortality, and white pine blister rust (*Cronartium ribicola*) and mountain pine beetle (*D. ponderosae*) killed most of the white pine. Root and butt rots have been a major cause of mortality in Douglas-fir and western hemlock the past two decades and have often resulted in windthrow or windbreak of stems. Windthrow has been a major cause of mortality of western hemlock and Pacific silver fir. Heavy mistletoe (*Arceuthobium campylopodum* f. *laricis*) infections weaken and probably kill western hemlock and, to a lesser extent, Pacific silver fir.

Net change in stand volume is closer to zero for the 36-yr period because extensive mortality offset the large gross volume growth (Table 2, Figure 2). Total net growth was 277 ft³/ac or 990 bd ft/ac; per annum equivalents are 8 ft³/ac and 28 bd ft/ac. Such net growth resulted in a total increase of only 1 to 2% of 1947 volume and probably is not significantly different from zero.

Changes in Stand Structure and Composition

Although growth and mortality are essentially in balance for the stand as a whole, major differences occurred among individual species. Substantial net losses occurred in Douglas-fir and western white pine, whereas net gains were achieved by western hemlock, true firs, and western redcedar (Table 2).

Diameter distributions of principal tree species in 1947 and 1983 provide an indication of the changes occurring in stand structure (Figure 3). Douglas-fir lost 3.4 trees/ac, and surviving trees were generally in larger size classes. Diameters are distributed in the bell-shaped pattern typical of intolerant species in even-aged stands. There were no Douglas-firs in the 6-in dbh class in either 1947 or 1983. Western hemlock and true fir also had fewer trees (5.6 and 8.3, respectively) in 1983 than in 1947, and trees have grown into larger diameter classes. The diameters of both western hemlock and the true firs were distributed in an inverse-J pattern, typical of uneven-aged stands and tolerant species. Western redcedar gained an average of 1.0 tree per acre during the period. More than half the western redcedar stems were in the smallest size class, but there was a normal distribution of the remaining trees in the larger size classes.

The changing importance of various species or species groups to stand processes can be seen more clearly by comparing species in terms of their relative contribution to initial inventory, gross growth, ingrowth, and mortality (Table 3). Douglas-fir constituted 59% of the stand volume in 1947, but during the next 36 years contributed substantially less of the gross volume growth (34%), provided no ingrowth, and accounted for nearly half of all mortality. Western hemlock, on the other hand, contributed far more to gross growth on a percentage basis than it did to original stand volume; relative contributions to ingrowth and mortality are similar to each other and to initial stand volume (26 to 28%). The true firs contributed 11% of the gross growth and 60% of all ingrowth, even though they accounted for only 6% of initial stand volume. Western redcedar has more or less held its own in the stand. Western white pine was essentially eliminated from the stand by insects and disease.

DISCUSSION AND CONCLUSIONS

This 36-yr record of growth and mortality in a 450-yr-old stand illus-

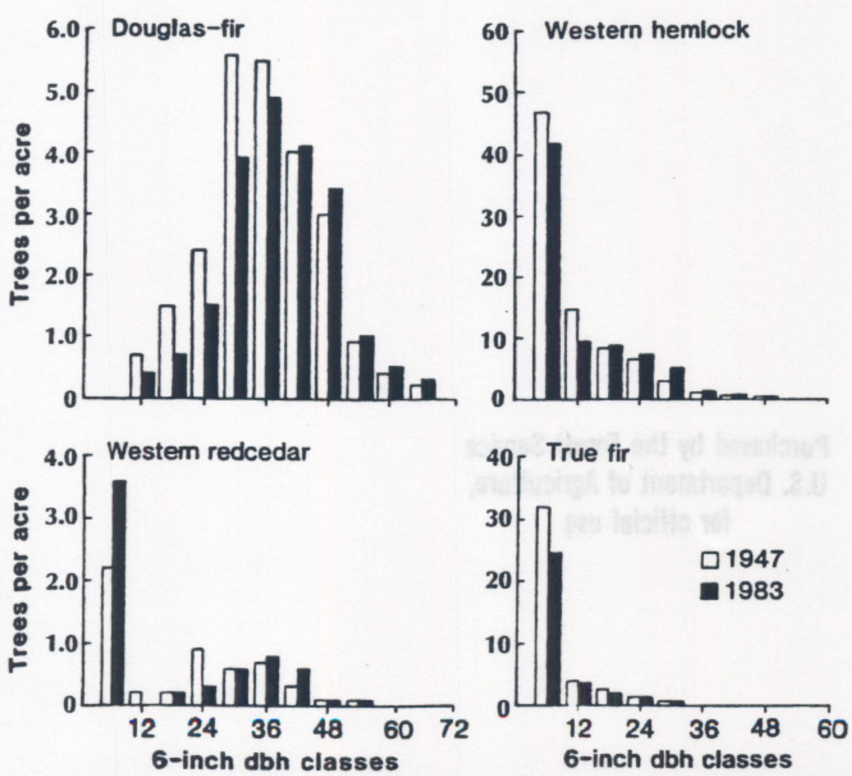

Fig. 3. Diameter distribution of principal species, by 6-in classes, in old-growth Douglas-fir–western hemlock stand in Thornton T. Munger Research Natural Area, 1947 and 1983.

Table 3. Species contributions to initial inventory, gross growth, ingrowth, and mortality between 1947 and 1983.

Species	Inventory, 1947	Gross growth	Ingrowth	Mortality
	% of total cubic feet			
Douglas-fir	59	34	0	49
Western hemlock	27	49	26	28
True firs[1]	6	11	60	8
Western redcedar	6	4	6	3
Western white pine	1	1	0	12
Miscellaneous	1	1	8	1
	Cunits per acre			
Total	132.9	33.8	0.1	31.0

[1] Grand, noble, and Pacific silver firs combined.

trates some patterns common to many old-growth Douglas-fir and western hemlock stands in the Pacific Northwest. Wood volume (and presumably total living biomass) have remained essentially constant, despite much activity in growth and development processes.

Gross volume growth was larger than many foresters might expect for an old-growth stand (94 ft^3/ac/yr). Such gross productivity is equivalent to about one-half of that in 60- to 100-yr-old Douglas-fir stands on sites of similar quality. Mortality in the old-growth stand was also very high (86 ft^3/ac/yr), and it essentially balanced gross growth. Mortality losses in younger stands, even when unthinned, on similar sites are much lower.

Net volume growth resulted in a 1983 stand volume that was only 1–2% greater than the 1947 volume. Such net growth was probably not significantly different from zero, especially in view of the fact that losses in usable volume caused by decay in living trees were not evaluated in our study. In contrast, net growth of Douglas-fir stands on rotations of 60 to 100 years averages about 150 ft^3/ac/yr (Curtis et al. 1982), nearly all of which is recoverable.

Important shifts have occurred (and are continuing to occur) in the relative importance of various tree species. The stand is shifting gradually from Douglas-fir dominance in the upper canopy to western hemlock; simultaneously, true firs and western redcedar are increasingly represented in the lower crown classes.

Demonstration of the ever-changing nature of old-growth stands is probably the most important contribution of this 36-yr record. Although the net change in timber volumes was nil, processes and changes are as dynamic as those observed in many much younger stands. Hence, characteristics or functions of old-growth stands cannot be guaranteed in perpetuity by simply preserving existing old-growth tracts. Where desired old-growth forests attributes are transient, long-term management strategies must include plans to recreate stands with those attributes. More information on patterns and rates of change in old-growth forests is clearly essential for identifying the nature and intensity of such problems. □

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