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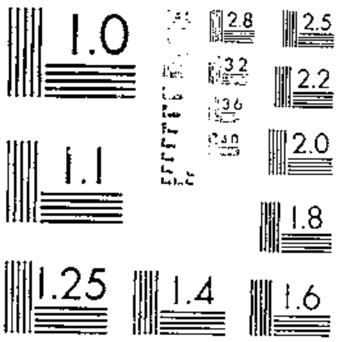
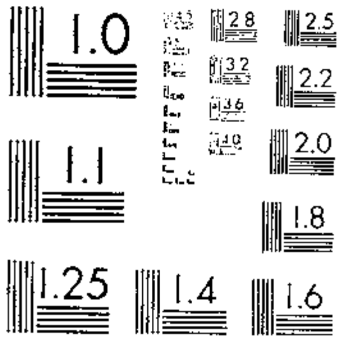


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963-A



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GROWTH OF DOUGLAS FIR TREES OF KNOWN SEED SOURCE

By Thornton T. Munger, *director*, and William G. Morris, *assistant silviculturist, Pacific Northwest Forest Experiment Station, Forest Service*

CONTENTS

INTRODUCTION

Very soon after the national forests of the Pacific Northwest were put under technical management and artificial reforestation was begun on them, questions began to arise as to the seed provenance that would give best results in both natural and artificial reforestation. Douglas fir (*Pseudotsuga taxifolia* (Lambert) Britton) being the all-prevailing and outstanding tree of the commercial timber zone of western Washington and western Oregon, the problem here centered in this one species. The natural range of this tree is very great, extending from sea level to altitudes of 5,000 feet or so and including soils varying from rich loams to almost sterile gravels. Wide variations exist, also, in the age, health, and crown development of the seed-bearing trees. It seemed probable that seed from certain localities would show hereditary traits that would render it especially suitable for regeneration on some sites but unsuitable for some other sites. It seemed probable also that for a given locality the quality of the seed and of the seedlings grown therefrom would vary somewhat with the age, health, and crown development of the parent.

A study of Douglas fir seed and its hereditary characteristics was therefore one of the first projects undertaken by the Wind River Forest Experiment Station[1] of the United States Forest Service.

[1] Superseded in 1924 by the Pacific Northwest Forest Experiment Station, Portland, Oreg.

The project was begun in 1912, in accordance with a brief working plan [2] written by the senior author in which the general purposes of the study were stated as follows:

(1) To determine from what class of tree the best seed for artificial reforestation may be obtained.

(2) To determine the influence of locality upon the seed collected for use in artificial reforestation.

(3) To determine what classes of Douglas fir make suitable seed trees to leave in logging operations.

The purpose was to test seed not from all parts of the wide range of Douglas fir but from the important commercial range of the species in western Oregon and western Washington.

In the 22 years since the project was initiated its personnel [3] has changed considerably. A great effort has been made, however, to preserve continuity of records and a standardized technique throughout the observations. The tests are, of course, still incomplete, and are in some respects unsatisfactory. The present report describes the experimental conditions and procedure, presents the results thus far obtained, and draws for the information of the forest manager some tentative conclusions as to seed-tree selection either in cutting operations or in artificial reforestation.

Each parent tree tested in this experiment may either have pollinated itself or have been pollinated by another tree. Data were obtained only on the trees from which the seed was collected. So far as altitude and latitude are concerned, all the trees within pollinating range of the cone bearer are almost certain to have been produced under the same influences as the cone bearer. As to other factors dealt with in this study, correspondence between the pollinating tree and the cone bearer is less certain. Those who have studied heredity traits through careful selection of both parents for several generations might at first think that knowledge of the cone-bearing parent only is not sufficient. Practically, however, it matters little whether, for example, the densely grown, infected, or old seed trees included in the study were or were not pollinated partly by trees of the opposite types; in reforestation by leaving seed trees after logging, and at present in collecting seed for planting, ordinarily the forester cannot control or identify the source of pollen. The data obtained in this study are presented not in an attempt to prove or deduce laws of heredity for Douglas fir but rather to show (1) the effects of using certain Douglas fir seed on areas differing in altitude, climate, or soil from those where the seed originated, and (2) the effects of using seed from certain old, densely grown, or infected trees.

It is very difficult to isolate the effects of any one of the numerous factors affecting tree growth. In a low-altitude plantation established with seed from high- and low-altitude sources, for example, any growth difference observed may be due to difference not in

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[2] MUNGER, T. T. OUTLINE FOR THE STUDY OF THE SOURCE OF DOUGLAS FIR SEED IN RELATION TO ITS VITALITY AND VIABILITY AND THE VIGOR OF THE SEEDLINGS GROWN THEREFROM. Pacific Northwest Forest Experiment Station. 1912. (Unpublished manuscript.)

[3] C. P. Willis had a particularly active part in the initial stages of seed collecting and testing. J. V. Hofmann was directly in charge of the project from 1913 to 1924 as director of the Wind River Forest Experiment Station; the senior author had a part in initiating the project, and since 1924 has been responsible for it as director of the Pacific Northwest Forest Experiment Station. Among many others who have had a part in conducting it are R. H. Weidman, E. J. Hanzlik, C. J. Kraebel, A. A. Griffin (deceased), H. V. Brown (deceased), A. G. Simson, L. A. Isaac, E. L. Kolbe, and the junior author.

altitude but in soil. For a test of the comparative growth of trees having seed sources of good and poor soil quality, the two seed-collection areas should be far enough apart to make pollination between them impossible; otherwise, the seed collected may be of a strain, developed through years of cross-pollination, that is equally well adapted to both soils. Even if the possibility of cross-pollination is thus eliminated, a true comparison of soil effects may not result if the stands on the two areas, respectively, are of two strains differing markedly in inheritable vigor. Furthermore, there are so many different soil types that a comparison of the growth of progeny from parents on two soil types is only a very small beginning.

Evidence of the hereditary significance of seed source has been observed in Europe for many decades. In most of the early experiments in this field seed from certain localities was planted to determine the stock's hardiness and rate of growth in certain other localities. A few experiments dealt with the heritability of tree-form characteristics. Some of the European investigators were Cieslar, Engler, Oppermann, Hauch, Reuss, Wibeck, and Kienitz. Forest-tree heredity studies in the United States began with tests of geographic races, and lately have included tests of different types of individual trees in the same locality as sources of seed for reforestation. Reports on seed-source experiments in this country have been published by Austin, Bates, Eckbo, Pearson, and Wahlenberg. A résumé of both European and American seed-source studies has been published by Roeser (*6*).[4]

Münch (*3*), in discussing observed growth and form differences between "local races" of the same botanical species, attributes the formation of these races to the selective action of factors such as length of growing season, summer warmth, frost, soil, disease, snow, light, and wind. Finding two races of pine making rapid growth not explainable on the basis of warmth and length of growing season, he suggested that a combination of especially favorable environmental factors affecting growth may bring about development of a physiologically superior race.

European observation (*3*) has shown that in general tree strains from a cold climate if grown in a warm climate may burst their buds too early and be frozen by a late spring frost, and that the oaks respond in the opposite way. At the Wind River forest nursery (altitude 1,100 feet), Columbia National Forest, Wash., trees grown from seed from several different high-altitude sources have been observed by J. F. Kümmel to burst their buds 1 or 2 weeks before those derived from low altitudes.

The geographic distribution of each plant species is largely controlled by the temperatures required for its life processes. On high mountains, usually temperatures are lower than at low altitudes and the warm-weather season is shorter. Two places identical in altitude and latitude may have extremely different mean temperatures, especially if one of them is near the seacoast; but for the most part, altitude is a roughly accurate gage of temperature differences. Owing to the relation of temperature to altitude and the lack of specific temperature data in mountainous regions, foresters have come to

[4] Italic numbers in parentheses refer to Literature Cited, p. 41.

use altitude as an index of a tree's suitability for a locality outside its natural range.

The difference in growth between the Pacific coast and Rocky Mountain forms of Douglas fir was early recognized in Europe, where the species was introduced about 100 years ago. The botanical and silvical characteristics of the Pacific coast ("green") and Rocky Mountain ("blue")[5] forms have been described by Frothingham (*4*) in considerable detail. The Pacific coast form usually grows much more rapidly, but is less hardy than the Rocky Mountain form when planted in a cold climate. Seed from the States of Colorado, New Mexico, Montana, Idaho, Washington, and California was planted in Russia in 1910 by Count von Berg of Sagnitz, Livonia. A brief report on this planting summarized by Zon (*9*) showed that when the seedlings were 2 years old those of the Pacific coast form derived from western Washington were considerably taller than those of the Rocky Mountain form derived from Colorado. During the severe winter of 1910–11 all the western Washington stock was badly frozen, but the Colorado stock showed practically no damage. During the next winter no seedlings of either form were frozen.

The present experiment differs in two respects from many previous tests of the growth rate of a given species as affected by geographic seed source: (1) The different seed sources are all within the range of a single previously recognized form (the Pacific coast form) of the species, and (2) the study includes extensive tests of several individual types of seed trees in the same localities.

The conclusions presented here should not be taken as wide generalizations: they apply only under the specific growing conditions affecting the parent trees and plantations of the study.

EXPERIMENTAL PROCEDURE AND CONDITIONS

SELECTION OF PARENT TREES AND COLLECTION OF SEED

In the fall of 1912 a liberal quantity of cones was collected from 120 different trees. The parent trees were selected to typify various conditions as to age, site quality,[6] stand density, fungus infection, and altitude. They grew in 13 different localities within the principal range of the Pacific coast form of Douglas fir, from northwestern Washington to central-western Oregon, shown in figure 1. Not all the classes of seed-source conditions covered by the study were represented in every one of the localities; in some of the localities, however, more than one set of conditions were found. Altogether, 26 seed collections were made. Seed was collected from 3 to 11 trees in each of these instances except three, in which collection was from 1 or 2 trees only; thus, in general, it was possible to submerge any individual characteristics of single trees through combining the data for several trees in one locality. Throughout the study, the records of the seed and progeny of each parent were kept separate

[5] Technical varietal names tentatively applied to the two forms are: Pacific coast form, *viridis*; Rocky Mountain form, *glauca*.

[6] The term "site quality" denotes the forest-productive capacity of an area, determined by the composite effect of all climatic and soil conditions. Five site qualities are recognized here, of which I is the best.

and were identified by number alone. The localities and the numbers of individual trees from which seed was collected and used are shown, for each set of conditions, in table 1.

The seed-source areas varied in altitude from 100 to 3,850 feet. The parent trees ranged in age from 15 to 600 years, and in diameter

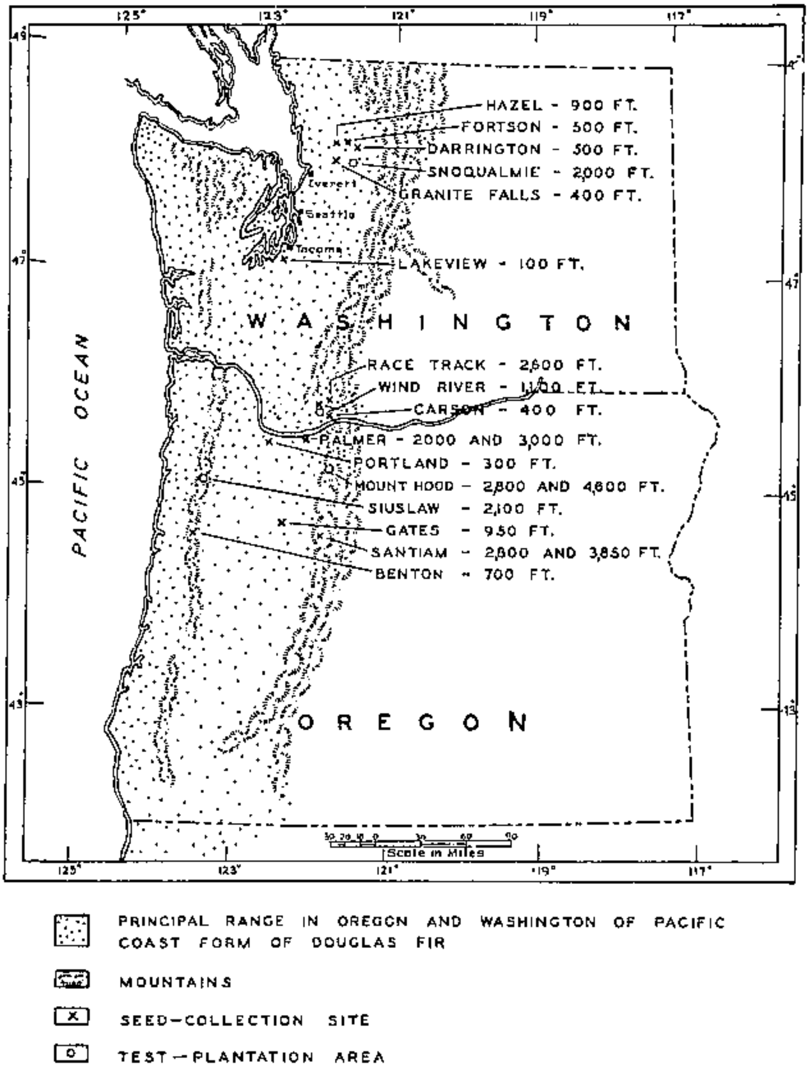

FIGURE 1.—Location and elevation of seed-collection sites and test-plantation areas.

from 3 inches to 6½ feet. They differed in crown development, according to stand density. Most of them were free of fungus infection, but seven were infected with red ring rot (*Trametes pini* (Trot.) Fr.).

TABLE 1.—*Class, location, and altitude of seed sources, and numbers of parent trees tested*[1]

Class	Locality	Altitude	Parent trees tested
Stands at low altitude:			
Open-grown, aged—		*Feet*	*Number*
15 to 40 years	Carson, Wash.	400	11
	Darrington, Wash.	500	7
	Portland, Oreg.	300	3
	Gates, Oreg.	900	[2] 8
55 to 70 years	Darrington, Wash.	500	4
	Benton, Oreg.	700	4
100 to 200 years	Carson, Wash.	400	6
	Gates, Oreg.	950	[2] 6
More than 200 years	Gates, Oreg.	950	3
Crowded, aged—			
60 to 100 years	Granite Falls, Wash.	400	4
	Fortson, Wash.	500	4
	Benton, Oreg.	700	3
	Gates, Oreg.	950	[2] 2
More than 200 years	Granite Falls, Wash.	400	4
	Hazel, Wash.	900	4
Stands at high altitude, aged—			
20 to 100 years	Race Track, Wash.	2,600	5
	Palmer, Oreg.	2,000	5
	Santiam, Oreg.	2,800 3,850	8
More than 200 years	Palmer, Oreg.	3,000	6
	Santiam, Oreg.	3,000	4
Stands on poor gravel soil, aged—			
35 to 40 years	Lakeview, Wash.	100	4
150 years	do.	100	4
Fungus-infected trees (aged more than 200 years).	Wind River, Wash.	1,250	4
	Gates, Oreg.	1,000	2
Uninfected trees (aged more than 200 years).	Wind River, Wash.	1,400	[3] 5

[1] Parent trees are tabulated here according to the comparisons in which their progeny were used in this study, not according to every description applying to them. For example, those entering into comparison as representing "stands on poor gravel soil", and so tabulated, are not included in the number tabulated under "Open-grown trees growing at low altitude", although they met that description also.

[2] These trees were used also in a comparison of growth of stock derived from rocky soil and from loam soil.

[3] The trees tabulated as uninfected include only those tested in comparison with infected trees at Wind River. 3 uninfected trees in the Gates locality were tested in comparison with the infected trees tested there.

The collections were so made that various parent-tree groups could be set off in pairs ostensibly similar in all respects except one, with the purpose of detecting the effect of this one variable on the progeny. Factors the effects of which it was sought to detect in this way were: (1) Altitude—high or low; (2) soil—good or poor; (3) age—young, medium, or old; (4) fungus infection—infected or not infected with red ring rot; (5) stand density—open or dense grown.

A detailed description of each parent tree was recorded, covering such points as size, age, dominance, character of crown, and health, and with it a description of the tree's environment. A profile sketch of the tree was made, showing shape and proportions of crown and location of cones.

The seed extracted from each lot of cones was subjected to a series of physical measurements, and to germination tests in the greenhouse and in the nursery.

SOWING AND PLANTING

Seed of each parent tree was sown in the nursery in the springs of 1913 and 1914. The stock was transplanted within the nursery when 1 year old, and when 2 years old was outplanted on deforested areas each typical of conditions common in the Douglas fir region.

The outplanting was done in the spring, as soon as the snow went off, by the one-man, grub-hoe method. Care was exercised to keep the rows straight and to space the trees uniformly 7 by 7 feet. The progeny of each parent formed a single row. In 1915, for some parent trees 10 or 15 transplants were used in each plantation; for most parents, 20; and for 11 parents, 100. The same diagram of planting was used on all plantation areas in 1915, so that the progeny of any given parent formed the same row, by number, in every plantation. The areas planted in 1915 were each 700 feet long and 238 feet wide. In 1916, an area 700 feet by 77 feet was planted adjacent to each 1915 plantation. In 1916 the number of transplants available was considerably smaller than in 1915; for no parent tree was it more than 10 per plantation, and for several parent trees it was less. The planting diagram used differed from that used in 1915.

At the time of planting, identification stakes were placed at the end of each row and at the corner of each plot and a numbered metal tag (about the size of a 5-cent piece) was loosely wired to each transplant. This tag showed the number of the parent tree and the number of the transplant in the row. The planted trees were carried in the record books and computations by these numbers; for example, the tenth tree in the row of progeny of parent tree 67 was referred to as 67–10.

Where pedigreed stock was insufficient to complete rows, fillers of nonpedigreed stock were used so as to equalize spacing and competition. No border strips were planted around the test plantations, however; and where pedigreed trees failed to become established, no trees were planted in the blanks.

PLANTING AREAS

Since it was desired to test the planting stock on deforested areas in several contrasting situations, the planting was done in four widely separated localities: One in the southern Washington Cascades (on the Columbia National Forest), one in the northern Washington Cascades (on the Snoqualmie National Forest), one in the northern Oregon Coast Range (on the Siuslaw National Forest), and one in the northern Oregon Cascades (on the Mount Hood National Forest). In the last-named locality three planting areas were used, at different altitudes. In each of the others a single area was used. All the planting areas had been burned over, and some of them had been cut over before being burned. None of them had ever been cultivated in any way. Each was located with a view to maximum uniformity throughout as to slope, aspect, soil, and drainage. The locations of the planting areas are shown in figure 1. The areas are more particularly described as follows:

The Wind River area is about 40 miles northeast of Portland, Oreg., and 7 miles north of the point at which the Columbia River has cut a gorge through the axis of the Cascade Range almost to sea level. It lies on the flat, mile-wide floor of the mountain valley drained by Wind River, a tributary to the Columbia River. Its elevation is 1,100 feet; walls of the valley rise abruptly to 2,400 feet. The soil is a deep, sandy, clay loam. Normal mean daily minimum temperature for the coldest month is 26° F. Growth begins about

May 15. During the growing season the daily maximum temperatures are higher and the precipitation is less than on any of the other plantation areas. Mean monthly precipitation, according to Weather Bureau records for the years 1912–21, is more than 4.1 inches for all months except June, July, and August, and for them is 2.2 inches, 0.6 inch, and 1.1 inches, respectively. The site quality is III. The old-growth timber was cut in 1909, and a slash-disposal fire followed the logging. Vine maple (*Acer circinatum* Pursh.) and bracken (*Pteridium aquilinum* Kuhn.) form a rank growth on the area at present.

The Snoqualmie area is about 28 miles east of Puget Sound, in the valley of the South Fork of the Stillaguamish River. Its elevation is 2,000 feet. The 1916 plantation is on a bench north of the river and 600 feet above it. (The 1915 plantation was abandoned in 1918 because of rodent damage.) The climate, as in most other portions of the foothills area bordering on the territory directly influenced by the Pacific Ocean and Puget Sound, is not severe in its extremes. The winters are similar to those of the Wind River area, the summers cooler than at Wind River. Summer rainfall is characteristically much greater than on the other test areas or in most localities in the Douglas fir region. Mean monthly precipitation, according to Weather Bureau records, for 9 nonconsecutive years ended with 1926 was more than 5.3 inches for all months except June, July, and August, and for them was 4.0, 1.9, and 3.0 inches, respectively. The soil is a gravelly, sandy loam. Growing conditions are better than on any of the other plantation areas, and are comparable to the best in the Douglas fir region. Similar nearby areas on which the timber is still standing are classified as of site quality II.

The Siuslaw area is 10 miles inland from the Pacific Ocean and 60 miles southwest of Portland, Oreg. It represents the equable moist conditions of the Oregon Coast Range, on which it is located 2,100 feet above sea level. The winter temperatures are less severe than on any of the other plantation areas, and the summers are marked by high relative humidities and frequent morning and afternoon fogs. Mean monthly precipitation, as estimated from Weather Bureau records for the period 1892–1916, is more than 5.9 inches for all months except June, July, and August, and for them is 3.6, 1.3, and 1.3 inches, respectively. Frequent fogs during summer months probably add considerably to the quantity of moisture made available for plant growth by precipitation. The best available estimates from Weather Bureau data indicate that the normal mean daily minimum temperature of the coldest month is not lower than 31° F. The soil is a well-drained, gravelly, clay loam. For Douglas fir the site quality is about II. The old-growth timber was killed by a crown fire many years before the plantations were established. A rank growth of salal (*Gaultheria shallon* Pursh.) and bracken covers the area at present. The 1916 plantation on this area showed such poor survival that it was abandoned.

The Mount Hood areas are very near the crest of the Cascade Range and 40 miles southeast of Portland, Oreg., in the Still Creek drainage basin. Areas A and B lie within 2 miles of each other, but at elevations differing by 1,800 feet. Area A is on a narrow bench just above the creek, at 2,800 feet elevation. Area B, shown in figure 2, is

2 miles upstream from A, near the top of the ridge, at 4,600 feet elevation. Area C was abandoned, owing to fire damage in 1917. Replicative lots of trees were planted on each area in 1915 and 1916. The Mount Hood areas are subject to winter cold and summer-night coolness typical of the mountains. At a nearby weather station the normal mean daily minimum temperature of the coldest month is 22.8° F. and the normal mean daily maximum temperature of the warmest month is 68°. On these areas the growing season is shorter than on any of the other plantation areas; only 4 months in the year have a normal mean daily temperature above 46°, whereas on the other plantation areas 6 or 7 months have mean temperatures above 46°. Douglas fir on the Mount Hood areas bursts its buds about June

FIGURE 2.—Mount Hood B plantation area, on a rugged, exposed slope at an altitude of 4,600 feet. When photographed, the planted trees were 16 years old from seed and 14 years in the field.

15, or 4 to 6 weeks later than on the other areas. Precipitation during the growing season is greater than at Wind River, about the same as on the Siuslaw area, and less than on the Snoqualmie area. Precipitation, according to data recorded during 1895–1922 at a Weather Bureau station 3 miles distant, averages more than 5.2 inches for each month of the year except June, July, and August, and for them averages 1.3, 1.6, and 1.9 inches, respectively. The lower area (A) has a more shallow soil than the areas in other localities, and the upper area (B) has a soil still more shallow. Much rock is mixed with the sandy loam topsoil, and there are rock outcroppings near each of the two areas. Humus was thin or lacking at the time of planting. The site quality of area A is IV and that of area B is probably about V.

The old-growth timber was killed by fire several years before the planting, and the burning was repeated, the last fire occurring in 1910. At the time of planting there were many snags but very little herbaceous or brushy growth on area B. Area A, because it had not been burned so severely, had more of this growth and some young trees (which were removed). Bracken, blueberry (*Vaccinium* spp.), and scrubby salal form the present low cover.

CARE OF PLANTATIONS

It was the plan of this experiment to give the planted trees no culture, so as to obtain data that would apply directly to untended extensive plantations. Soon it developed, however, that not all the areas and not all parts of individual areas were comparable in regard to competition. On some areas hardwood brush sprang up very abundantly and threatened to smother or retard the growth of many of the planted trees; on some, natural reproduction of Douglas fir threatened to deprive many of the planted trees of the space they were supposed to have. On these areas cleaning operations were carried out, in an effort to preserve equality of opportunity for each pedigreed tree. The Wind River area was cleaned twice. It cannot be said, however, that such equality was preserved for every individual tree, because the release weedings were not always made in time and because replacements were not made. So far as competition is concerned it may be that one lot averaged about the same as the next, but the difference among plantations in this respect was considerable.

PERIODIC EXAMINATIONS

All plantations were examined in both the spring and the autumn of 1915 and 1916, and in the autumn of 1917, 1918, 1919, 1921, 1923, 1925, 1928, and 1931. At each examination a record was made of survival. At fall examinations the total height of each surviving tree was recorded,[7] except on one or two occasions when height was taken on every fifth tree only. At first, measurement was in feet and inches, later, in feet and tenths. At some examinations a record was made of the cause of death or injury of any trees, of frost damage, of date of winter-bud maturity, and of seed bearing.

At times of periodic examination the numbered tags were moved to limbs higher on the trees, and when a tree reached sufficient size its tag was nailed loosely to the main stem at breast height. Missing tags were replaced (with embossed tags of strip metal). Though tags disappeared from a good many trees, it was always possible to identify such trees from the plantation diagram and the numbers on neighboring trees.

DAMAGE TO PLANTATIONS

The history of these plantations has shown strikingly, almost tragically, the number of damaging agencies to which small planted

[7] On the Siuslaw area, by 1931 the trees had made such growth that diameter measurement had become significant. Therefore, in that year both total height and diameter at breast height were taken. In future examinations, to be made in the fall of 1936 and at 5-year intervals thereafter, it is planned to measure diameters in all plantations in which the trees have reached appropriate size.

trees are exposed. In some cases damage has been so severe that a whole plantation had to be abandoned. In many cases, trees have been so injured that they had to be eliminated from computations. In other cases the number of trees in some lots has been so reduced that the basis for conclusions has been unduly narrowed.

In spite of the protection customary on the national forests, in 1917 a fire ran over parts of Mount Hood areas B and C. Area C was damaged to the extent that it had to be abandoned, and patches of trees were killed on area B with the result that the value of the records for some lots was destroyed. A fire reached the Wind River area in 1927, but was checked before it had damaged more than a few lots.

Immediately after the 1915 plantation on the Snoqualmie area was established mountain beaver (*Aplodontia rufa* Rafinesque) or rabbits, or both, killed so high a proportion of the trees that the plantation was abandoned. Elsewhere rodents destroyed such proportions of some rows as to weaken the data for certain lots.

On some of the test areas there were large numbers of snags from which chunks of bark or wood fell from time to time. In the Snoqualmie 1916 plantation, for example, each year a considerable number of planted trees were thus killed or so deformed that they had to be eliminated from the analyses.

In spite of precautions, trespass has affected the records for a few lots. In the Snoqualmie 1916 plantation, a trail was inadvertently slashed down a row or two. On Mount Hood area B a band of sheep browsed on some test trees, and on the Wind River area straying cows trampled some trees before a fence was built to keep them off.

Some frost damage occurred on the Wind River area. This is discussed on page 32. So far as has been observed, the test plantations have not suffered any extraordinary damage from such factors as wind, snow, ice, and soil erosion.

RESULTS

Data from the experiment were analyzed to determine the effect of various characteristics of parent stocks and individual parents upon (1) yield and size of cones and seeds, and germination of seeds;[8] (2) height growth; (3) mortality in various habitats; and (4) time of beginning spring growth (as indicated by bursting of buds). A byproduct of the study was information as to the growth rates of planted trees on areas of different site qualities.

The progeny surviving in 1931 on which conclusions could be based totaled about 8,500 on four 1915 plantations and about 2,800 on four 1916 plantations.

HEIGHT GROWTH OF VARIOUS STOCKS

METHODS OF ANALYSIS

Total height in the fall of 1931 was used as a measure of the comparative growth of the progeny from various parents. For trees

[8] The results from this part of the analysis have been presented in previous reports (5, 7, 8). They are summarized on p. 35.

planted in 1915, height in 1931 represents the result of growth during 19 seasons, including 2 seasons in the nursery; for trees planted in 1916, it represents the result of growth during 18 seasons. The height data for intervening years were not used [9] for this purpose because the object is to show the cumulative effect of heredity factors upon growth.

In most of the analyses the heights of progeny from several similar parents were averaged to show the effect of a certain parental characteristic upon growth of the offspring. The number of parents in each of two contrasted groups usually was not equal, and the number of progeny representing one type of parent was very often disproportionate to the number representing the opposite type. This made it necessary to have some exact measure of the significance of each average. As the first step in obtaining such a measure the standard deviation (σ) of the individual progeny heights, or scatter of the tree heights around the mean, was computed. Then the standard error [10] (SE) of the mean was computed by the formula $SE=\frac{\sigma}{\sqrt{N-1}}$, N being the number of items. The standard error is a reliable expression of significance, taking into consideration the consistency or regularity of the tree heights and also the number of trees. The standard errors are given with most of the averages tabulated here, to enable the reader to judge the significance of the differences in height growth of various lots of trees. In interpreting the results, the difference between two means was not considered significant unless it was three times the standard error of the difference ($SE_{diff}=\sqrt{SE_1^2+SE_2^2}$); that is, unless it was greater than the result obtained by squaring the standard errors, adding them, extracting the square root, and multiplying by 3. Averages based on 30 or more trees usually had a standard error equal to 5 percent of the mean. Most of the averages were based on at least 50 trees.

Any individual that was injured during its life in the plantation was eliminated from the basic growth data, if it was shorter than the average uninjured tree of the same lot. Any tree was eliminated, also, if it obviously had been subject to abnormal growing conditions. Altogether not more than 10 percent of the trees surviving in 1931 were so eliminated.

When these eliminations had been made the data still showed considerable irregularity in height growth of progeny of individual parents in individual plantations, indicating that some progeny were unnaturally stunted through the influence of some factor not identified.[11] This irregularity is illustrated in figure 3. In an

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[9] Data from the periodic measurements are utilized (p. 33), however, to demonstrate the progress of growth in each plantation as a whole, regardless of seed source. Later, these data from periodic measurements will show whether a given strain's rate of growth maintains the same relation to those of other strains until the trees reach maturity.

[10] Often termed "standard deviation of a mean."

[11] Uninjured trees as short as 5 feet sometimes occurred within 7 feet of trees, from the same parents, as tall as 25 feet. In many instances an abrupt break in the height level occurred in the same section of two or more adjacent parallel rows. In the Mount Hood–A 1915 plantation such a break runs up the slope, at right angles to the rows, through consecutive rows of progeny representing about 20 different parents. The irregular outlines of this break suggest those of a swath created by a fire starting at the foot of a slope and burning to the top. Variations in height within rows not attributable to injury or to obviously abnormal growing conditions may, of course, have been caused partly by inherent individual differences in vigor. It is thought probable that for the most part they are due to an undetected deficiency of the soil in parts of the planting areas. Fires, burning with uneven intensity, may destroy the fertility of a forest soil in

effort to avoid as far as possible the error of comparing the mean of a normal sample with the mean of a sample including a large proportion of unnaturally stunted trees, the upper quartile [12] was tried as a height measure. This height value was determined for the progeny of 20 different groups of parent trees used in 10 different comparisons. In every case, comparison of the upper quartiles showed the same result as comparison of the arithmetic means. Therefore, it was assumed that unnatural stunting of trees did not lower the arithmetic mean in one sample any more than in another, and the arithmetic-mean height was used throughout the analyses.

In order to detect any less pronounced differences in heights of adjacent trees, such as might have resulted from a gradual variation in site conditions between one part of a plantation area and another, the average height for each row was expressed as a percentage of the

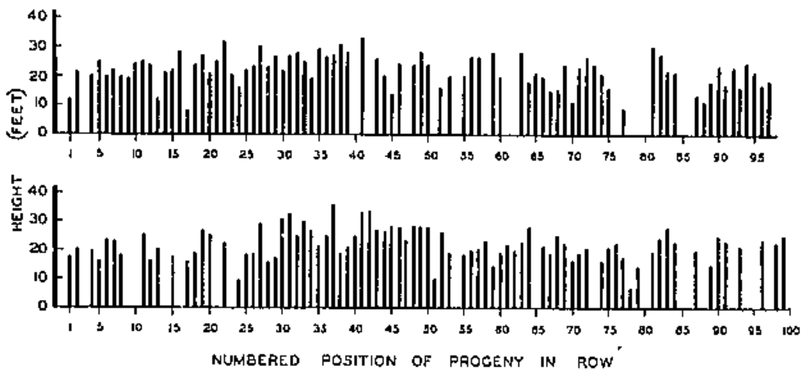

FIGURE 3.—Heights in 1931, in the Siuslaw plantation, of the progeny of 2 of the parent trees tested. (Each row consists of progeny of one of the parents. Damaged trees are omitted.) These progeny were grown in parallel rows 7 feet apart and 700 feet long.

mean of the average heights for all rows in the plantation and this percentage was written on a plat or diagram of the standardized arrangement of the rows in each planting. This made possible a direct comparison, for example, of the Carson progeny in the Mount Hood–A 1915 planting with the Carson progeny in the Siuslaw 1915 planting, in terms of the percentage by which each group exceeded or fell below the average for all stocks in the same planting. Direct comparison in terms of feet was not suitable, because, for example, in general the trees in the Siuslaw planting of 1915 were about 14 feet taller than those in the Mount Hood–A planting of that year. If it was found that a certain section of one plot produced trees 20 percent below the plantation average in height, whereas in all other plantations the same stock in that part of the plot was 15 percent above the average, and if the stock under consideration was derived from a locality resembling the planting locality in climate, then it was concluded that the growing conditions in that particular section of that plot were inferior to those on the remainder of the plot.

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irregular patches according to observations in a study in the Douglas fir region reported in the following: ISAAC, L. A. DEVELOPMENT OF DOUGLAS FIR SPACING-TEST PLANTING DURING THE FIRST FIVE YEARS. File Memorandum. Pacific Northwest Forest Experiment Station. 1931.

[12] The upper-quartile height value for 100 trees, for example, is the height of tree no. 76 when all trees are ranged according to height with the shortest first.

In that event, conclusions drawn from height analyses of the stock involved were tempered by knowledge of the variation in growing conditions. On this basis certain results (as is indicated later in table 9) must be considered in some degree unreliable.

The method used in making growth comparisons of progeny having high- and low-altitude seed sources differs from the method used in comparisons to determine the effects of parental age, growing space, infection, etc. A tree derived from a given altitude as compared with one derived from another altitude is very likely to be influenced by growth factors other than that of seed-source altitude. Therefore, a stock from a given elevation was compared not with a single stock from a different elevation but with the average of stocks from all elevations. If in a high-altitude plantation a stock of high-altitude source grew taller than the average of all the stocks tested in that plantation, and if in a low-altitude plantation this stock did not grow taller than the average of all stocks tested, the results would tend to indicate existence of a strain especially adapted to the growing conditions at high altitudes.

EFFECT OF AGE OF PARENT

To determine whether the age of the parent affected the growth of the progeny, average heights of progeny were compared for parent trees growing in the same locality and similar in all respects except age. The numbers of parent trees tested are shown in table 2. These comparisons were made for each plantation, the 1915 and 1916 plantings being treated separately. Height averages for the 47 pairs of parent-age groups are shown in table 3. In 23 cases the height of progeny from young parents averaged greater than that of progeny from old parents, in 22 cases it averaged less, and in 2 cases the heights of the two groups were equal. Only four of the comparisons show a significant difference (a difference three times as great as the standard error of the difference): Those for the Gates progeny in the Siuslaw plantation, the Lakeview progeny in the Siuslaw plantation, the Carson progeny in the Mount Hood–A 1915 plantation, and the Palmer progeny in the Mount Hood–A 1916 plantation. Comparisons not described here showed that progeny from middle-aged (100- to 200-year-old) parents did not markedly differ in height from progeny of either young or old parents. It is clear that age of the parent tree had no consistent or significant effect upon growth of the offspring.

TABLE 2.—*Numbers of parent trees tested in comparison of progeny from younger and older parents*

Age class [1] of parent (years)	Year when progeny were planted	Parent trees, by locality					
		Carson	Gates	Granite Falls	Palmer	Santiam	Lakeview
		Number	*Number*	*Number*	*Number*	*Number*	*Number*
17–100	1915	11	8	4	5	8	4
130+	1915	6	3	4	5	4	4
17–100	1916	9	8	4	5	5	4
130+	1916	6	3	3	4	3	3

[1] Actual ages or ranges of age for individual seed-source localities were as follows: Carson, 20–40 and 130–170; Gates, 17–30 and 200 upward; Granite Falls, 60 and 215–220; Palmer, 20–40 and 362–375; Santiam, 100 and 200 upward; Lakeview, 35–40 and 150.

TABLE 3.—*Heights of progeny from younger and older parents of each seed-source locality, averaged by individual plantations*

Plantation area and year of planting	Age class of parents	Average heights[1] of progeny in 1931, by seed-source locality					
		Carson	Gates	Granite Falls	Palmer	Santiam	Lakeview
	Years	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*
Siuslaw: 1915	17-100	21. 9 (±0. 48)	19. 3 (±0. 41)	24. 9 (±0. 50)	23. 1 (±0. 41)	17. 0 (±0. 31)	19. 2 (±0. 84)
	130+	22. 2 (±. 88)	21. 4 (±. 50)	24. 8 (±. 52)	21. 7 (±. 48)	16. 1 (±. 48)	23. 2 (±. 38)
Wind River:							
1915	17-100	13. 1 (±. 42)	16. 2 (±. 43)	23. 4 (±. 84)	18. 2 (±. 75)	15. 8 (±. 36)	16. 2 (±. 63)
	130+	12. 7 (±. 51)	17. 4 (±. 54)	22. 2 (±. 75)	18. 6 (±. 68)	14. 6 (±. 61)	16. 2 (±. 52)
1916	17-100	11. 6 (±. 53)	16. 5 (±. 65)	15. 2 (±. 87)	15. 2 (±. 68)	17. 5 (±. 78)	15. 2 (±1. 28)
	130+	12. 5 (±. 84)	[illegible]. 9 (±1. 09)	13. 4 (±1. 20)	13. 0 (±. 70)	16. 6 (±. 89)	15. 6 (±1. 54)
Snoqualmie: 1916	17-100	12. 5 (±. 56)	22. 6 (±. 85)	21. 4 (±1. 03)	18. 4 (±. 66)	17. 3 (±. 55)	18. 8 (±1. 14)
	130+	12. 9 (±. 79)	22. 9 (±1. 17)	19. 7 (±1. 11)	18. 8 (±. 66)	17. 9 (±. 72)	15. 3 (±1. 01)
Mount Hood-A:							
1915	17-100	5. 8 (±. 14)	8. 1 (±. 36)	7. 5 (±. 39)	7. 6 (±. 29)	7. 5 (±. 16)	5. 9 (±. 27)
	130+	4. 6 (±. 20)	6. 9 (±. 26)	7. 4 (±. 36)	8. 0 (±. 32)	7. 5 (±. 25)	6. 1 (±. 19)
1916	17-100	6. 3 (±. 31)	5. 6 (±. 24)	7. 0 (±. 38)	3. 9 (±. 27)	4. 7 (±. 39)	9. 7 (±. 46)
	130+	6. 4 (±. 43)	6. 3 (±. 39)	7. 7 (±. 46)	5. 0 (±. 21)	5. 9 (±. 43)	9. 3 (±. 58)
Mount Hood-B:							
1915	17-100	5. 4 (±. 15)	5. 7 (±. 22)	7. 8 (±. 32)	6. 5 (±. 19)	6. 1 (±. 17)	6. 6 (±. 21)
	130+	6. 1 (±. 30)	6. 3 (±. 25)	7. 0 (±. 29)	6. 0 (±. 33)	6. 9 (±. 27)	5. 9 (±. 18)
1916	17-100	----------	4. 4 (±. 18)	5. 4 (±. 22)	6. 1 (±. 40)	6. 5 (±. 34)	4. 1 (±. 36)
	130+	----------	5. 0 (±. 46)	5. 1 (±. 35)	5. 8 (±. 28)	6. 4 (±. 36)	3. 9 (±. 37)

[1] Numbers in parentheses are standard errors.

In order to obtain a more simple set of comparisons, the average heights of progeny from the younger and from the older Carson parents in all the 1915 plantations were averaged, each plantation test being given a weight of 1, and the same process was carried out for each other source of seed and for the 1916 as well as the 1915 series of plantings. The results are given in table 4. The paired items in the table show that for some seed sources the height of progeny from younger trees averaged slightly greater than the height of progeny from older trees, but that for other seed sources the superiority was reversed. None of the differences is large enough to be significant from a statistical standpoint.

TABLE 4.—*Heights of progeny from younger and older parents of each seed-source locality, averaged by year of planting*

Seed-source locality	Average height in 1931 [1]			
	1915 plantings of progeny from parents aged—		1916 plantings of progeny from parents aged—	
	17 to 100 years	150 years or more	17 to 100 years	150 years or more
	Feet	*Feet*	*Feet*	*Feet*
Carson	11.5 (±0.29)	11.4 (±0.47)	10.1 (±0.35)	10.6 (±0.70)
Gates	12.3 (±.33)	13.0 (±.40)	12.3 (±.52)	12.6 (±.85)
Granite Falls	15.9 (±.62)	15.4 (±.60)	12.2 (±.70)	11.5 (±.75)
Palmer	13.8 (±.47)	13.6 (±.45)	10.9 (±.60)	10.7 (±.55)
Santiam	11.6 (±.19)	11.3 (±.28)	11.5 (±.55)	11.7 (±.65)
Lakeview	12.0 (±.49)	12.8 (±.38)	11.9 (±.67)	11.0 (±.68)

[1] The averages given are means of the averages for the 4 plantings of each year, a weight of 1 being given to each planting. Numbers in parentheses are standard errors.

EFFECT OF SITE QUALITY OF SEED-SOURCE AREA

Opportunity to study the effect of site quality of seed-source area on growth of progeny was afforded by the seed collections from Lakeview, Wash. The Lakeview parents grew on the Steilacoom Plains (8 miles south of Tacoma, Wash.), glacial outwash plains of coarse gravel soil. Here Douglas fir is part of a sparse, slow-growing stand including ponderosa pine and oaks, species characteristic of dry sites. These plains are perhaps the best example in western Oregon or western Washington of a large area with very poor site quality due to the structure and composition of the soil. To a depth of at least 6 feet the soil consists mostly of gravel, with a mixture of sand. It contains very little humus, and has practically no surface vegetable litter. The mean annual precipitation of 40 inches is sufficient for excellent tree growth; but excessive drainage of the gravelly soil makes the site very dry during the latter part of the growing season, when only 2 inches of rain falls in a 2-month period. The good tree growth in localities not many miles distant having better soil is proof that the character of the soil is the principal factor in the poor site quality at Lakeview. More than 1,000 progeny of the Lakeview parents were grown in the test plantations.

These progeny showed no effects of the poor quality of the soil upon which the seed was developed. In nearly every plantation, in 1931 the Lakeview stock equaled or exceeded the average height of all stocks tested (table 5). In the Siuslaw plantation, where the height average for all lots was 21.4 feet, 179 Lakeview trees averaged 22.0 feet. In the Wind River 1916 plantation the Lakeview stock averaged 15.4 feet in height, whereas the plantation average was only 14.1 feet. The data for the Lakeview stock therefore give no basis for a belief that poor site quality of the area upon which the parent grows lessens the vigor transmitted to the progeny. Since such trees as now occupy the Steilacoom Plains are the descendants, probably not many generations removed, of trees on better soils several miles away, this finding does not answer the question whether over a long period poor site quality might weaken the strain.

TABLE 5.—*Heights of progeny from parents growing on the poor-quality Lakeview, Wash., site, compared with those of all progeny*

Plantation area and year of planting	Average height,[1] in 1931, of Lakeview progeny	Mean of average heights, in 1931, of all stocks
	Feet	*Feet*
Siuslaw: 1915	22.0 (±0.39)	21.4
Wind River:		
1915	16.2 (±.41)	16.8
1916	15.4 (±.97)	14.1
Snoqualmie: 1916	17.1 (±.82)	17.9
Mount Hood-A:		
1915	6.1 (±.16)	6.4
1916	9.6 (±.37)	6.6
Mount Hood-B:		
1915	6.1 (±.14)	6.1
1916	4.0 (±.25)	5.1
Average	12.0 (±.26)	11.8

[1] Numbers in parentheses are standard errors.

The seed collections from Gates, Oreg., afforded the only opportunity to compare the offspring of several parent trees in the same locality growing on soils with and without a large proportion of rock. Of the Gates parents tested, eight were growing on a rocky soil and eight otherwise similar were growing on a sandy loam soil. Progeny from the two groups were planted side by side on the rocky Mount Hood-B area, on the "shot" sandy clay loam Wind River area, and on three intermediate grades of soil. Table 6 gives the heights of progeny from each group. For all test plantations together, the heights of progeny from the rocky-soil group averaged 12.3 feet and those of progeny from the sandy-loam-soil group averaged 11.9 feet. The difference of 0.4 foot does not show that one group is any better than the other, being less than the experimental error. Comparison of the "rocky" and "loam" groups on each plantation shows slight differences in average height favoring sometimes the former and sometimes the latter, none of the differences being large enough to indicate a difference in hereditary vigor.

None of the localities from which seed was collected in this experiment is extremely dry. Those having the least rainfall during the growing season are Gates and Portland; those having the greatest are Granite Falls and Darrington. During July and August Gates and Portland receive little more than 0.5 inch precipitation per month, whereas Darrington and Granite Falls receive more than twice that amount. A growth comparison between the two pairs of stocks was afforded on the Snoqualmie and Wind River plantation areas, which are approximately alike in all respects except that the Wind River area normally receives only 2 inches of rain in June and 0.6 inch in July whereas the Snoqualmie area normally receives 4 inches in June and 2 in July. The height growth of the Granite Falls and Darrington (rainy-habitat) stocks was from 3 to 35 percent above average in both the Snoqualmie (rainy) and the Wind River (dry) planting localities. These stocks grew as well on the Wind River area as the Portland and Gates (dry-habitat) stocks, or better. The dry-habitat stocks grew well both on the Wind River area and on the Snoqualmie area. (These comparisons appear later in table 9.)

TABLE 6.—*Heights of progeny from parents growing on contrasting soils at Gates, Oreg.*

Plantation area and year of planting	Average heights,[1] in 1931, of progeny from parents growing on	
	Rocky soil [2]	Sandy loam soil [3]
	Feet	*Feet*
Siuslaw: 1915	19.3 (±0.41)	19.6 (±0.30)
Wind River:		
1915	16.2 (±.43)	15.0 (±.29)
1916	16.5 (±.65)	14.4 (±.54)
Snoqualmie: 1916	22.6 (±.85)	23.1 (±.67)
Mount Hood-A:		
1915	8.1 (±.36)	7.4 (±.16)
1916	5.6 (±.24)	5.4 (±.23)
Mount Hood-B:		
1915	5.7 (±.22)	5.2 (±.13)
1916	4.4 (±.18)	4.4 (±.23)
Average	12.3 (±.29)	11.9 (±.20)

[1] Numbers in parentheses are standard errors.
[2] Data are for progeny of 8 parents aged 17 to 30 years.
[3] Data are for progeny of 8 parents aged 100 to 200 years.

EFFECT OF GROWING SPACE OF PARENT

Progeny of parents growing in dense stands, with narrow crowns less than one-third the length of their stems, and progeny of open-grown parents with widespreading crowns extending nearly to the ground, were included in each of the lots of Gates and Benton stock. At both places the open-grown and crowded parent trees were found so near together that they are not likely to have differed in any respect other than growing space. The height of 200 progeny from 4 open-grown Gates seed trees, in all test plantations combined, averaged 11.9 feet (table 7); that of 600 progeny from 2 crowded small-crowned Gates seed trees averaged 12.6 feet. The difference of 0.7 foot does not indicate any practical superiority, being less than the experimental error. In several plantations (table 7), progeny from open-grown parents reached greater average heights than progeny from crowded parents. Of the 1,300 saplings of Benton parentage, those from 4 open-grown parents averaged 11.7 feet in height and those from 3 crowded parents averaged 12.1 feet.

Here also, the difference is too small to indicate any hereditary influence.

TABLE 7.—*Heights of progeny from open-grown and from crowded parents*

Plantation area and year of planting	Average heights,[1] in 1931, of progeny from given seed sources			
	Gates, Oreg., parents		Benton, Oreg., parents	
	Open-grown [2]	Crowded [3]	Open-grown [2]	Crowded [4]
	Feet	*Feet*	*Feet*	*Feet*
Siuslaw: 1915	10.7 (±0.34)	18.9 (±0.86)	25.9 (±0.53)	26.0 (±0.66)
Wind River:				
1915	15.6 (±.31)	20.2 (±.96)	15.3 (±.85)	18.5 (±1.06)
1916	14.3 (±.66)	16.0 (±1.37)	13.7 (±1.13)	11.6 (±1.00)
Snoqualmie: 1916	23.7 (±1.19)	23.1 (±.96)	18.8 (±.85)	21.5 (±.71)
Mount Hood-A:				
1915	6.0 (±.17)	8.5 (±.71)	4.5 (±.29)	4.5 (±.38)
1916	5.8 (±.29)	4.3 (±.34)	5.5 (±.35)	5.5 (±.26)
Mount Hood-B:				
1915	5.1 (±.22)	5.8 (±.50)	4.7 (±.27)	5.8 (±.50)
1916	4.1 (±.27)	4.4 (±.66)	5.2 (±.37)	3.6 (±.46)
Average	11.0 (±.21)	12.6 (±.61)	11.7 (±.52)	12.1 (±.67)

[1] Numbers in parentheses are standard errors.
[2] Data are for progeny from 4 parents.
[3] Data are for progeny from 2 parents
[4] Data are for progeny from 3 parents.

EFFECT OF FUNGUS INFECTION IN THE PARENT

Heritability of effects of fungus infection was tested through the planting of seed collected at Gates and Wind River from trees infected with red ring rot[13] and from similar uninfected trees growing side by side with them. In each case the two lots of seed were handled and planted in the same manner, and the progeny from infected trees were grown directly beside the progeny from uninfected trees. No significant difference has appeared between the two classes of progeny, at any period from the time the seed germinated. Both classes look the same and have grown at the same rate. In 1931 the Gates progeny from infected parents averaged 12.6 feet in height and those from uninfected parents averaged 12.7 feet in height. These values are both means of eight individual plantation averages. They represent the heights of 174 progeny from 2 badly infected parent trees and 470 progeny from 3 uninfected parent trees growing nearby. When average heights are considered for each of the test plantations separately (table 8), it is seen that in some tests of the Gates progeny those from uninfected trees were slightly taller, but that in others those from infected trees were taller. In no case were the differences significant.

In 1931 the offspring from infected Wind River parents averaged 11.5 feet in height and those from uninfected Wind River parents averaged 12.1 feet in height, a difference that is less than the experimental error and therefore fails to indicate any advantage in healthy parentage. These averages are based on 324 progeny from

[13] *Trametes pini*, other common names for which are conk rot, ring-scale rot, honeycomb rot, and pecky wood rot. According to studies by Boyce (2), this fungus causes 80 percent of all decay losses in living Douglas fir.

4 infected parents and 297 from 5 uninfected parents. In five of the seven separate test plantations of Wind River stock, better growth was made by progeny from uninfected trees. In the two remaining tests, however, the average height of progeny from infected parents was greater; and only in the Wind River and the Mount Hood-A 1915 plantations were trees from uninfected parents significantly taller than those from infected parents. The plantings at Wind River may not offer a fair comparison of the two types of seed source: there some of the progeny from infected trees happened, unlike any of the progeny from uninfected trees, to be planted on a strip of soil that appears to be poor in quality. In the two test plantings where there was a significant difference in growth in favor of uninfected parent trees, moreover, half the rows from infected parents were taller than half the rows from healthy parents; in other words, while in these plantings the uninfected parents as a group yielded better results than the infected parents as a group, in each case individual parents in the infected group yielded better results than certain individuals in the uninfected group.

TABLE 8.—*Heights of progeny from parents infected with red ring rot*[1] *and from uninfected parents*

Plantation area and year of planting	Average heights,[2] in 1931, of progeny from given seed sources			
	Wind River parents		Gates parents	
	Infected[3]	Uninfected[4]	Infected[5]	Uninfected[6]
	Feet	*Feet*	*Feet*	*Feet*
Siuslaw: 1915	20.3 (±1.65)	21.6 (±0.83)	20.2 (±0.61)	21.4 (±0.50)
Wind River:				
1915	13.9 (±.64)	16.8 (±.60)	18.0 (±1.05)	17.4 (±.51)
1916	15.3 (±.80)	13.0 (±.97)	13.4 (±1.29)	15.9 (±1.09)
Snoqualmie: 1916	15.2 (±1.14)	12.8 (±1.01)	25.2 (±1.29)	22.9 (±1.17)
Mount Hood-A:				
1915	5.0 (±.12)	5.8 (±.21)	7.9 (±.41)	6.9 (±.26)
1916	6.6 (±.67)	8.1 (±.42)	5.8 (±.56)	6.3 (±.39)
Mount Hood-B:				
1915	6.5 (±.24)	6.9 (±.28)	5.6 (±.40)	6.3 (±.25)
1916			4.7 (±.44)	5.0 (±.46)
Average	11.5 (±.40)	12.1 (±.42)	12.6 (±.58)	12.7 (±.35)

[1] *Trametes pini.*
[2] Numbers in parentheses are standard errors.
[3] Data are for progeny from 4 parents in the 1915 plantations and progeny from 3 parents in the 1916 plantations.
[4] Data are for progeny from 5 parents.
[5] Data are for progeny from 2 parents.
[6] Data are for progeny from 3 parents.

EFFECT OF ALTITUDE OF SEED-SOURCE AREA AS RELATED TO ALTITUDE OF PLANTING AREA

The seed used in the present experiment was collected at 12 different altitudes, ranging from 100 to 3,850 feet; and seedlings from all the seed sources were planted at altitudes of 1,100, 2,100, 2,800, and 4,600 feet in nearly the same latitude and at an altitude of 2,000 feet 200 miles farther north. The growth made by stock of given seed-source altitudes when planted on areas of given altitudes is shown in table 9.

TABLE 9.—*Height, in each test plantation, of trees derived from each seed-source locality, by altitude of source area and of plantation area*

Source of seed		Parent trees from which seed was collected	Progeny planted on each plantation area in—		Average height [1] in 1931 of trees in given plantations at given altitudes								
Locality	Altitude		1915	1916	Siuslaw (altitude 2,100 feet) series of 1915	Wind River (altitude 1,100 feet) series of— 1915	Wind River 1916	Snoqualmie (altitude 2,000 feet) series of 1916	Mount Hood-A (altitude 2,800 feet) series of— 1915	Mount Hood-A 1916	Mount Hood-B (altitude 4,600 feet) series of— 1915	Mount Hood-B 1916
	Feet	*Number*	*Number*	*Number*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Granite Falls	400	8	150	70	[2] 116 (±1.9)	[2,4] 135 (±3.4)	103 (±5.1)	[2] 115 (±4.3)	[2] 116 (±4.2)	112 (±4.5)	[2] 116 (±3.9)	101 (±5.1)
Darrington	500	11	220	110	[2] 128 (±1.9)	[2] 107 (±2.5)	107 (±4.1)	[2] 112 (±3.8)	103 (±2.8)	[2,4] 129 (±4.5)	107 (±2.6)	98(±10.0)
Palmer	{2,000 3,000}	21	220	100	104 (±1.4)	[2] 119 (±2.5)	102 (±3.5)	103 (±2.7)	[2] 122 (±3.3)	[3,4] 68 (±2.7)	102 (±2.7)	[2] 116 (±4.9)
Lakeview	160	8	230	70	103 (±1.8)	96 (±2.5)	109 (±6.9)	96 (±4.6)	95 (±2.5)	[2,4] 115 (±5.6)	100 (±2.3)	78 (±4.9)
Gates	950	21	680	210	[3] 93 (±.9)	98 (±1.3)	109 (±3.5)	[2] 120 (±2.0)	[2,4] 111 (±1.7)	[3] 85 (±2.3)	[3] 92 (±1.8)	88 (±2.4)
Santiam	{2,800 3,850}	12	540	80	[3] 78 (±1.3)	[3] 92 (±2.0)	[2,4] 122 (±4.4)	98 (±2.4)	[2] 117 (±2.0)	[3,4] 77 (±3.9)	103 (±2.1)	[2] 127 (±4.9)
Fortson	500	4	80	40	[3,4] 84 (±2.5)	107 (±3.1)	103 (±5.6)	97 (±1.5)	103 (±4.7)	95 (±5.5)	103(±13.0)	96 (±5.7)
Hazel	900	4	70	30	[3,4] 78 (±2.8)	107 (±3.6)	104 (±5.7)	86 (±5.8)	106 (±4.5)	95 (±5.8)	105 (±6.6)	86 (±8.8)
Wind River	1,300	9	165	70	98 (±3.2)	92 (±2.9)	94 (±4.3)	[3] 81 (±5.0)	[3,4] 81 (±2.3)	[4] 110 (±4.5)	110 (±2.9)	----------
Race Track	2,600	5	180	40	100 (±2.6)	88 (±3.2)	87 (±5.6)	84 (±5.3)	[3,4] 91 (±2.8)	[4] 106 (±4.4)	98 (±3.4)	----------
Benton	700	7	110	65	[2] 121 (±1.9)	98 (±4.2)	90 (±5.8)	[2] 112 (±3.2)	[3] 70 (±2.8)	[3] 83 (±3.3)	[3] 84 (±3.9)	88 (±6.0)
Portland	300	3	60	30	[3,4] 90 (±3.0)	96 (±3.8)	89(±12.1)	[2] 116 (±3.7)	[3] 83 (±4.7)	106 (±8.3)	89 (±6.6)	116 (±8.6)
Carson	400	17	410	130	103 (±2.1)	[3] 77 (±1.9)	[3] 85 (±3.3)	70 (±2.5)	[3] 81 (±1.9)	95 (±2.1)	[3] 92 (±2.3)	----------
All seed sources	----	----			[5] 21.4	[5] 16.8	[5] 14.1	[5] 17.9	[5] 6.4	[5] 6.6	[5] 6.1	[5] 5.1

[1] The averages given were derived by computing the mean height of each of the 13 stocks in a given plantation, averaging the 13 means, and converting the average height of each stock to a percentage of this average. Numbers in parentheses are standard errors.

[2] Significantly taller than the average of all stocks in the same plantation.

[3] Significantly shorter than the average of all stocks in the same plantation.

[4] The deviation from average height is believed to be due in part to site-quality variation within the plantation area.

[5] Feet.

The Siuslaw and Mount Hood–B test areas offered the greatest contrast in the climatic conditions that vary with altitude. The Mount Hood area has the greatest elevation, 4,600 feet, and has a mountain climate. The Siuslaw area, although not so low as the Wind River area, is very near the coast, and therefore has a climate milder than that of any of the other plantation areas.

Stock from the Santiam National Forest, in the high Cascade Range, that was planted on the Siuslaw coastal test area grew at a particularly slow rate. In 1931 it was 22 percent below the average height for all stocks on that area, averaging 16.7 feet as compared with a general average of 21.4 feet. The general height average for this plantation was not matched by the average for the progeny of even one of the 12 Santiam parents. It appeared improbable that the poor growth of this stock resulted from soil deficiency. The averages for the Santiam stock were based upon 368 normal progeny; this is a goodly number for these test purposes, as is shown by the small standard error of 0.28 foot.

Progeny from these same mountain parents grew well in the high-altitude plantings. In the 1916 plot on the Mount Hood–B area, at 4,600 feet altitude, where the climate is like that of its seed-source locality, the Santiam stock averaged 27 percent taller than the average for all stocks. Thus it was as much above average at home as it was below average away from home. This Mount Hood average was based upon 51 progeny from 11 parents. On the adjoining plot planted in 1915, where 277 Santiam progeny were available for height-growth analyses, that group averaged 3 percent taller than the average for all stocks. On the lower-altitude Mount Hood plantation area, at 2,800 feet, the Santiam stock was 17 percent above the general height average; here this stock (506 trees) averaged 7.5 feet, whereas all stocks averaged 6.4 feet. The 1916 series on this plantation area cannot be used for comparison, because the Santiam stock planted in that year was placed in a section where the soil is not nearly so good as in the sections where the low-altitude strains were planted.

A second mountain stock, from sources at 2,000 and 3,000 feet altitude near Palmer, Oreg., grew as well as the average in the coastal Siuslaw plantation. In all plantations, the rows of Palmer stock adjoined the rows of Santiam stock. Whereas the Santiam stock on the Siuslaw area was 22 percent shorter than the plot average, the Palmer stock there (143 trees) was 4 percent taller than the plot average (table 9).

At high altitudes, the Palmer stock made approximately the same growth as the Santiam stock. In the Mount Hood–B 1916 planting, at 4,600 feet altitude, the Palmer stock (81 trees) was 16 percent taller than the average for all stocks. In the adjacent 1915 planting the Palmer stock (175 trees) about equaled the average height for all stocks. In the Mount Hood–A 1915 plantation, at 2,800 feet, the Palmer stock (197 trees) was 22 percent (1.4 feet) above the average height for all stocks. Growing close to the Santiam stock, the Palmer stock in the Mount Hood–A 1916 series was handicapped by the poor soil quality mentioned previously, and its poor growth is not considered to represent fairly its inherent vigor. In general, the stock from Palmer grew as well as the average at low altitudes and better than the average at high altitudes.

The third mountain stock was derived from an altitude of 2,600 feet near Race Track Ranger Station, 7 miles from Wind River. Like the Palmer stock, it grew as tall as the average on the Siuslaw coastal test area. At the intermediate altitudes of Wind River and the Snoqualmie, it did not grow so well as the average stock. Unfortunately test conditions handicapped the Race Track trees in three of the Mount Hood plantings, so that the results are not clear. In the fourth, the Mount Hood–B 1915 planting, the Race Track stock nearly equaled the average height of all stocks.

Of the low-altitude stocks tested that from Benton, Oreg., in particular, has exhibited very little adaptability to higher-altitude growing sites. This stock comes from the coastal hills in west-central Oregon (fig. 1). On the coastal Siuslaw area, which has a climate similar to that of Benton, the Benton trees (65 progeny from 7 parents) were 4.5 feet, or 21 percent, taller than the average (table 9). Even the shortest group of progeny from any one Benton parent was 12 percent taller than the average for the tract. This coastal stock grew under the same test conditions as the Santiam mountain stock, which grew so poorly in the coastal plantation—in fact, it was directly adjacent to several rows of the Santiam mountain stock; but the coastal trees averaged 8 feet taller than the nearest rows of mountain stock.

In contrast with its superior growth when planted near home, the Benton stock made the poorest growth of all stocks when planted on the Mount Hood test areas. In the 1915 planting on the Mount Hood–A tract at 2,800 feet altitude, the Benton stock was only 70 percent as tall as the average (table 9); whereas the average height for all stocks was 6.4 feet, that for the Benton stock was only 4.5 feet. This difference is significant, inasmuch as there were 88 Benton progeny and the standard error of the average height was only 0.18 foot. Each of the seven rows of progeny representing Benton parents was from 22 to 49 percent below the plantation average for all stocks. The lots of trees growing on each side of the Benton stock were much taller. Similarly in the 1916 series, the Benton stock as a whole was only 83 percent as tall as the plantation average. The average heights of the progeny of individual Benton parents ranged from 73 to 92 percent of the general plantation average.

Growth of the Benton stock on the Mount Hood–B tract, at an altitude of 4,600 feet, was far below the average for all stocks there. In the 1915 series the Benton stock (47 trees) averaged 16 percent shorter than all stocks, 5.1 feet in contrast with 6.1 feet. In the nearby 1916 series the Benton stock averaged 12 percent less in height than all stocks; but this result failed to show significant inferiority, because the variation among the 42 Benton progeny was so great as to give a standard error of 6 percent.

The data show clearly that the Benton stock is not suited to the locality of the Mount Hood plantations, in the Cascade Range; on the other hand, they show just as clearly that it is well adapted to the locality of the Siuslaw plantation, near the seacoast.

The heights of the Palmer, Santiam, and Benton stock in the Mount Hood–B 1915 plantation and in the Siuslaw plantation are contrasted in figure 4.

The Carson, Wash., seed-source locality is at low elevation and has a relatively mild climate, with night temperatures in the early spring months perhaps higher than those of any other of the seed-source localities. Like the stock derived from Benton, the Carson

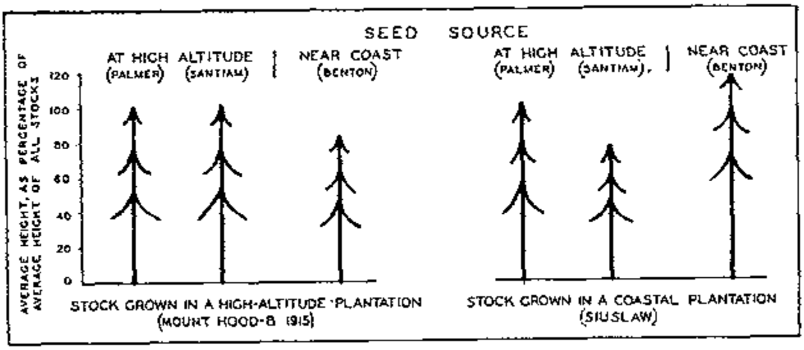

FIGURE 4.—Heights of Douglas fir stocks derived from mountain sites and from a coastal site, in a plantation at high altitude and in a coastal plantation. (Each of the height values shown was derived as follows: The mean height, in feet, of each of the 13 stocks in a given plantation was computed; the 13 means were averaged; and the average height of each stock was converted to a percentage of the average of the 13 means.)

FIGURE 5.—A 1925 view of some of the Carson stock in the Siuslaw plantation.

stock grew best on the Siuslaw plantation area (fig. 5). This was the only test area where it equaled the height average of all stocks. On the other plantation areas, on each of which several hundred progeny from Carson were grown, the Carson stock was invariably inferior to nearly all others. Even at Wind River, only 7 miles from their seed source, the Carson trees did not grow well; this may be due to the fact that the nights during the early part of the growing season are much colder at Wind River than at Carson. In the Mount Hood plantations the Carson stock was significantly shorter than the average of all stocks. In the Mount Hood–A 1915 plantation, where it was represented by 346 trees, it was 16 percent below the average height, being only 5.4 feet high as compared with an average of 6.4 feet. Here the progeny of only 2 of the 16 Carson parent trees excelled the height average of all stocks. In the nearby 1916 series, again, the Carson progeny were shorter than the average. In the 1915 planting on the higher Mount Hood–B tract this stock, represented by 209 trees, was 8 percent shorter than the average.

Several stocks grew equally well in nearly every plantation; that is to say, in comparison with the average for all stocks they ranked about the same no matter where they were planted. An example is the Granite Falls stock. These trees were from 3 to 35 percent taller than average in each of the eight plantations (table 9). At high altitudes they grew about as well as the Santiam mountain stock, and at low altitudes they grew better than most lowland stocks. The Granite Falls seed-source locality would be classified as of low altitude, and of comparatively mild climate. From a climatic standpoint there is no obvious explanation of the stock's adaptability to the Mount Hood locality.

A second strain exhibiting wide adaptability was that from Darrington, a locality 20 miles northeast of the Granite Falls seed-source area and at nearly the same elevation. The Darrington stock did not consistently average as tall as the Granite Falls stock; but it did not show any distinct signs of a climatic handicap in the mountain plantations, and it grew taller than any other stock in the coastal plantation. At Darrington the climate is much more mild than at the Mount Hood–B plantation site, the mean annual temperature being higher by 6° F. The buds usually burst more than a month earlier at Darrington, but that tendency did not render the Darrington stock subject to late spring frost damage on the Mount Hood–B area. A third stock exhibiting the same relative success at high and low elevations was that from Palmer, results with which are described on page 22.

DIFFERENCES AMONG STOCKS FROM VARIOUS LOCALITIES

Although such factors concerning the parent tree as age, soil, rainfall, growing space, and infection showed no effect on the height growth of the progeny in this experiment, the height growth of stocks from some localities was consistently superior to that of stocks from other localities. The observed differences in growth, resulting from factors or combinations of factors that have not been identified, distinguish what may be termed "locality strains."

In every plantation, the average height of the Granite Falls stock was greater than the average height of all stocks. In the Siuslaw plantation it was 116 percent of the mean of all stock averages (table 9), 24.9 feet as compared with 21.4 feet. Here the stock was represented by 102 progeny derived from 8 parent trees. That the superiority of Granite Falls stock was consistent among the progeny of different parents is indicated by the fact that the standard error was only 1.9 percent. In the Wind River plantation of 1915, the stock of Granite Falls parentage averaged 35 percent taller than the average of all stocks. This remarkable superiority may have been due in part to better soil conditions where the Granite Falls rows were located than nearby where the other stocks were tested. In the 1916 planting on the same tract, the Granite Falls stock was slightly taller than the average. On the Mount Hood–A area, at 2,800 feet altitude, the Granite Falls stock in the 1915 planting was 16 percent taller than the average. In the corresponding 1916 planting the Granite Falls stock failed to show so clear a superiority. Here it averaged 12 percent taller than all stocks, but the large variation among individuals made it doubtful that the average was significant. On the higher Mount Hood–B test area, the Granite Falls stock in the 1915 planting averaged 16 percent taller than the average of all stocks. In the corresponding 1916 planting, the height of the Granite Falls stock was slightly superior to the average of all stocks. In the Snoqualmie plantation, this stock was 13 percent taller than average. There is no doubt that, in general, the Granite Falls parents produced the most vigorous progeny tested in this experiment.

The second most vigorous stock was that derived from Darrington. This stock showed marked superiority in four plantations, and elsewhere was slightly better than the average. In the Siuslaw planting the height of the Darrington trees (164 progeny from 11 parents) was 128 percent of the average for all stocks, 27.3 feet as compared with 21.4 feet. Growth of adjacent rows gave no indication that the unusual height growth of the Darrington stock in this plantation was due to any extra-good soil conditions where the Darrington progeny grew. On the Wind River test area, the 1915 Darrington stock was 7 percent taller than the average of all stocks. Again, in both the Snoqualmie and the Mount Hood–A 1916 plantings the Darrington trees were significantly taller than the average. In the 1916 Wind River and 1915 Mount Hood–B plantations, the Darrington stock was taller than the average; but the difference was not clearly significant, because of the variation in individual heights indicated by the standard error. In the Mount Hood–A 1915 and Mount Hood–B 1916 plantings, the Darrington stock was no better than the average of all stocks. It was handicapped in the latter plantation, however, by poor growing conditions. Clearly, the Darrington stock possessed inherent qualities that caused it to excel the growth average of the 13 stocks tested even where its environment was greatly different from that of the parent trees.

The strikingly superior growth of the Granite Falls and Darrington stocks is not a result of testing these stocks in climates better suited to them than to others. On several test areas where both of them excelled other stocks in growth, the climate was no more similar to those of the localities from which they were derived than to the native climates of the Gates, Fortson, Hazel, or Wind River stocks.

In extreme contrast with the good growth of the Granite Falls and Darrington stocks is the very poor growth of the Carson stock. As table 9 shows, the height of the Carson stock did not come within 12 percent of the height of either the Granite Falls or the Darrington stock in any of the plantings. In the Snoqualmie plantation, the Carson trees averaged 8 feet shorter than the Granite Falls and Darrington trees. As is brought out under altitudinal effects, the climate may have been too cold for the Carson strain in all the plantation localities except the Siuslaw. Whatever the explanation of the poor growth, there is no doubt that this particular stock, the test of which included progeny of 17 trees scattered over a range of three-quarters of a mile, was not desirable for planting purposes.

The rank of all 13 stocks in height growth, as determined by averaging results in seven test plantings, is shown in figure 6.

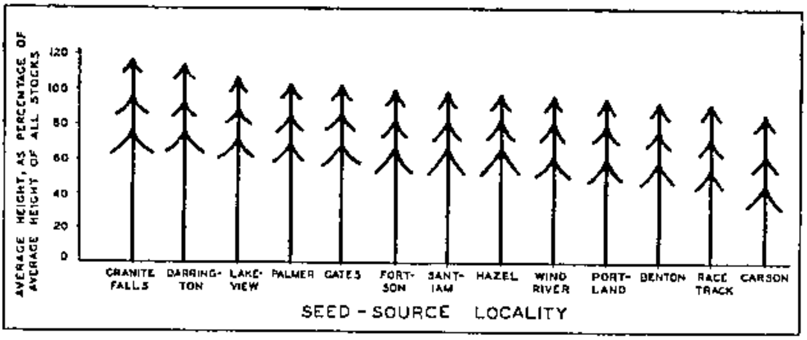

FIGURE 6.—Heights of the 13 Douglas fir stocks tested, in 7 plantings (the Mount Hood–B 1916 planting was excluded because some stocks in it had been destroyed by fire). Each of the height values shown was derived as follows: (1) The mean height of each of the 13 stocks, in feet, in a given plantation was determined; (2) the 13 means were averaged; (3) the mean height of each stock was converted to a percentage of the average obtained in step 2; (4) the percentages for a given stock in the 7 plantations were averaged.

SUPERIORITY OF INDIVIDUAL PARENTS

Comparisons of individual parents in the same locality as to quality of offspring were made as follows: (1) The mean height of the progeny of each parent was computed; (2) the means for all parents in a given locality were averaged; and (3) each of the means derived in step 1 was expressed as a percentage of the corresponding mean derived in step 2.

The greatest number of parent trees in any one locality tested in this experiment was 21, and, with two exceptions, the least was 3 (table 1). The height data failed to show that the progeny of any parent tree ranked in all plantations either significantly above or significantly below the average for progeny of all trees in the same locality. The progeny of only 12 of the 120 parents ranked significantly above or below average in three-fourths of the plantations. It was concluded that the difference in transmissible vigor among individual parents on each seed-collection area of the experiment was not so great but that thoroughly reliable averages representing locality stocks could be obtained by using as few as seven parents per seed-collection area.

MORTALITY

Analyses were made to show the effect on mortality of climate and several other factors such as age of parent, infection of parent, seed-source locality, and density of parent stand.

On rugged, burned-over, uncultivated forest land not every tree in a given plantation has an equal chance to survive the first year, owing to nonuniformity of planting technique and of surface-soil and shade conditions. Unequal mortality in a given plantation during the first year might obliterate a relationship between source of seed and mortality in later years. Also, replicative test plantations as widely scattered as those in this experiment may differ widely in seedling losses during the first year owing to differences in weather before, during, and after planting. Because of these inequalities, in this study the data for first-year mortality were analyzed separately. They showed no relation between mortality and source of seed. Accordingly first-year mortality data were eliminated from the comparisons. Mortality percentages were computed from the number of trees alive 1 year after planting and the number alive in 1923, after which year little mortality occurred. Progeny destroyed by fire, rodents, wind breakage, snow breakage, falling trees, and other factors clearly not related to their inherent vitality were eliminated from the mortality compilations.

The mortality percentages, given in table 10, show no significant difference in the ability of the various stocks to establish themselves and survive on any of the test-plantation areas. Low-altitude stock from a coastal climate survived well on the highest-altitude plantation area; and high-altitude stocks lived as well as the other stocks in the low and mild-climated plantations.

TABLE 10.—*Mortality*[1] *in the test plantations, from the second year after planting to 1923, inclusive*

Source of seed		Mortality of trees in given plantations at given altitudes							
Locality	Altitude (feet)	Siuslaw (2,100 feet) series of 1915	Wind River (1,100 feet) series of—		Snoqualmie (2,000 feet) series of 1916	Mount Hood-A (2,800 feet) series of—		Mount Hood-B (4,000 feet) series of—	
			1915	1916		1915	1916	1915	1916
		Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Darrington	500	5	7	11	13	6	9	3	10
Fortson	500	4	11	0	0	1	5	16	3
Hazel	900	4	8	0	0	5	7	24	3
Granite Falls	400	5	4	3	6	2	6	8	1
Lakeview	100	5	8	1	21	2	6	5	3
Wind River	1,300	5	5	1	7	2	13	7	------
Race Track	2,600	3	7	16	0	3	13	4	------
Carson	400	9	11	4	3	3	10	11	------
Palmer	{2,000 / 3,000}	5	4	6	2	1	7	1	4
Portland	300	3	10	7	0	0	3	0	10
Gates	950	4	6	4	4	1	9	2	7
Santiam	{2,800 / 3,850}	5	7	1	0	1	7	6	1
Benton	700	7	17	9	2	4	9	6	9
Average		5	8	5	4	2	8	7	5

[1] Exclusive of that caused by accident.

Parent-tree factors such as age and infection showed no effect on survival.

The plantations differed little as to mortality from physiological causes, even though there was such a wide range in the climates and soils that striking differences occurred in growth. Despite the great difference in environmental conditions between the Siuslaw area and the Mount Hood–B area, for example, the plantations on these two areas differed in mortality by only 2 percent. The greatest mortality difference between any two plantations was 6 percent.

DIFFERENCE AMONG STOCKS AS TO DATE OF BURSTING BUDS

Observations were made on the Wind River plantations in the springs of 1933 and 1934 to determine whether the different stocks differed inherently as to date of beginning growth. The plantations were examined when about one-third of the trees had burst their buds and it was possible to distinguish three classes of trees—those with all their buds open, those with some of their buds open, and those with no buds open. Each tree was carefully inspected and classified. Wide differences appeared between some of the stocks, as is shown by table 11. When examined in 1933 more than 65 percent of the trees from Lakeview, Carson, and Portland seed had burst their buds, so that the needles were out and the new shoots were noticeably elongated. In contrast, not more than 5 percent of the trees derived from Darrington, Hazel, Fortson, and Benton had burst their buds.

TABLE 11.—*Stages of bud bursting in the Wind River plantations, June 9, 1933*

Seed-source locality	Progeny with—		
	Needles out [1]	Buds bursting [2]	All buds tight
	Percent [3]	*Percent* [3]	*Percent* [3]
Granite Falls	22 (±11.5)	29 (±9.0)	49 (±12.0)
Darrington	5 (±2.8)	27 (±8.3)	68 (±8.0)
Palmer	22 (±7.1)	53 (±6.6)	25 (±6.5)
Lakeview	66 (±11.5)	20 (±6.0)	14 (±6.7)
Gates	38 (±6.2)	45 (±5.0)	17 (±5.5)
Santiam	33 (±10.0)	45 (±12.8)	22 (±8.8)
Fortson	5 (±5.0)	13 (±12.5)	82 (±11.9)
Hazel	0	23 (±11.2)	77 (±11.2)
Wind River	22 (±9.0)	34 (±13.0)	44 (±10.5)
Race Track	36 (±11.3)	32 (±11.2)	32 (±14.4)
Benton	2 (±2.0)	35 (±7.5)	63 (±7.3)
Portland	87 (±3.3)	13 (±3.3)	0
Carson	71 (±8.8)	23 (±5.7)	6 (±4.4)
Average	31	30	39

[1] Needles spread out on entire tree, and new shoots noticeably elongated.

[2] Buds bursting on most but not all branches (buds on lower branches usually open later); needles not entirely free from the effects of being compacted within the bud sheaths, so that on the greater part of the tree they have not spread out in a mature brushlike arrangement.

[3] The percentage of progeny in each stage was computed separately for each parent and the values for all parents in a given locality averaged. Numbers in parentheses are standard errors.

To simplify comparison of the different stocks, the percentages for each seed-source locality were assigned weights as follows: Needles out, 3; buds bursting, 2; all buds tight, 1. When the three weighted percentages for each stock were added the stocks were found to rank in the following order as to time of bud bursting in 1933 and 1934, the strain bursting its buds earliest being placed first:

1933		*1934*	
Portland	Wind River	Carson	Wind River
Carson	Granite Falls	Portland	Granite Falls
Lakeview	Benton	Lakeview	Darrington
Gates	Darrington	Gates	Benton
Santiam	Fortson	Santiam	Fortson
Race Track	Hazel	Race Track	Hazel
Palmer		Palmer	

That the order was so nearly identical in the 2 years is especially significant for the reason that the growing season in the Wind River plantations began 2 weeks later than normal in 1933 and 2 weeks earlier than normal in 1934. The percentage of trees with open or bursting buds, for all stocks, averaged 61 on June 9, 1933, and 43 on May 3, 1934.

Complete weather data are available for only 6 of the 13 localities in which seed was collected, but knowledge of weather conditions in localities similar to those for which instrument records are lacking makes possible rather dependable comparisons of all seed sources as to spring temperatures. When the various stocks were divided into three classes according to characteristics of the spring climate at the seed source, a close relation was found between that climate and the progress of bud bursting at Wind River. The first class is formed of stock from low-altitude plains and valleys having relatively warm spring days and nights; the second, of stock from high altitudes where both days and nights are cold until late in the season; and the third, of stock from foothill valleys where in spring the days are warm but owing to cold-air drainage the nights are cold. For these three classes the proportion of trees in the Wind River plantations having all their buds still closed on June 9, 1933, is as follows:

	Percentage of trees with all buds tight
1. Warm spring days and nights:	
Portland	0
Carson	6
Lakeview	14
2. Cold spring days and nights:	
Santiam	22
Palmer	25
Race Track	32
3. Warm spring days and cold spring nights:	
Gates	17
Wind River	44
Granite Falls	49
Benton	63
Darrington	68
Hazel	77
Fortson	82

It is evident that the stocks in group 1 were the first to open their buds, those in group 2 followed, and those in group 3, with one exception, were last. This succession is shown also by the 1934 data.

In their native localities the stocks of group 1 have been observed to open their buds about 3 weeks earlier, and those of group 2 about 3 weeks later, than native Douglas fir stock at Wind River. In the localities where the stocks of group 3 are native. Douglas fir opens its buds at about the same time as at Wind River.

To verify the differences in date of bud bursting observed at Wind River, the Mount Hood plantations were examined in 1933 according to the same procedure. On the Mount Hood areas the season of growth begins later, because of the higher elevations; so this examination was made 3 weeks later than the Wind River examination. None of the trees in the plantings at 4,600 feet elevation had fully exposed their new needles, and 87 percent of the trees in those plantings as a whole had not begun to burst their buds. However, more than 40 percent of the trees of the Carson and Portland stocks were in the bud-bursting stage, substantiating Wind River evidence as to the early bud-bursting habit of these stocks. In the Mount Hood–A plantings, at 2,800 feet elevation, about 90 percent of the trees had fully exposed their needles and the remainder were bursting their buds. Here the Fortson, Hazel, Darrington, and Benton stocks were the last to open their buds, showing the same tardy response to spring conditions as they showed at Wind River.

In neither pair of Mount Hood plantations, at the time when they were examined, was growth in the best stage of advancement to indicate clearly the differences between stocks. In the plantations at 4,600 feet too few trees had burst their buds, and in the plantations at 2,800 feet too many had already released their needles and elongated their shoots. In both cases the number of trees in each of the three stages of bud bursting was insufficient to permit complete numerical comparisons among all stocks. The great interval between the earliest and the latest opening of buds was, however, demonstrated very clearly.

Tardiness in beginning annual growth did not lessen a stock's chance of making the same height growth as a stock having an early start. Of the four stocks that began growth latest in the season, the Darrington and Fortson stocks were above average height and the Hazel and Benton stocks were only slightly below average. One of the stocks bursting their buds early, that derived from Carson, made very poor height growth (table 9).

FROST INJURY

The great significance of an inherited tendency for a stock to begin growth very early in the season lies in the danger of damage by late spring frost. Observations before and after a late spring frost on the Wind River plantation area yielded considerable data regarding the relation of weather to bud bursting and frost injury in the various stocks.

An examination on May 31, 1933, showed that the Carson and Portland progeny were the only ones the buds of which had opened to any great extent; that many of these trees had begun to elongate their shoots, and that others had not broken the bud sheath. A few scattered individuals of other stocks had begun to open their buds, but in nearly all cases these early-opening trees were less than 1 percent of the total number. During the night of May 31, 1933, the cooperative Weather Bureau station at Wind River recorded a minimum temperature of 29° F. No temperature less than 36° had previously been recorded since May 10, and for the last 8 days in May the mean maximum temperature was 59° and the mean minimum 42°; hence the 29° minimum on May 31, although it was only 3° below freezing, was an abrupt change. The effect of that sudden change on the succulent new shoots of the Carson stock was very noticeable in the afternoon of June 1, not more than 12 hours after the freezing. The new shoots, normally a light-green color, had turned yellow. In another day they had become reddish brown.

On June 1 and 2, systematic notes were made on all trees that had been frosted. Most of the buds that were only partly open had been injured, while most of those that were either closed or entirely open had escaped injury. The Carson stock had been most susceptible to the frost; of all the Carson trees with new needles exposed, 40 percent were injured. Most of the freshly injured trees bore dead, brown tufts of partly developed needles, evidence of frost injury in previous years. A few trees frozen in 1933 showed no signs of previous injury, and some trees bearing the marks of freezing in former years were not frozen in 1933.

The Carson seed-source locality and the Wind River plantation locality are only 7 miles apart by air line, but Carson is 700 feet lower. Carson lies in the Columbia River Gorge, where the prevailing west winds have free passage, and therefore has few calm nights with cold air settling from the hills above. The Wind River area lies in a level valley where cold air settles from high surrounding hills on calm spring nights. The normal mean daily minimum temperature for May is 47° F. at Carson and 39° at the Wind River plantation area. An average difference of 8° in minimum temperature is highly significant, especially near the lower temperature extreme at which trees function. Buds of the native stock at Carson burst from 3 to 4 weeks earlier than buds of native stock growing near the Wind River plantations. Frosts following bursting of the buds seldom occur at Carson. At Wind River a short period of warm weather approximately coinciding with the period of bud bursting at Carson probably is sufficient to start growth in the Carson stock. The first warm period often is followed by colder weather, with frosts at night.

At Portland the spring climate is nearly the same as at Carson, and Douglas fir bursts its buds at about the same time. However, the Portland stock at Wind River, in the same stage of growth as the Carson stock and similarly exposed, was not frozen.

Occasional trees from high-altitude sources had exposed their needles and been frozen. These trees had been injured by frost in previous years, also. The few individuals of high-altitude stocks that habitually burst their buds early in the Wind River plantations, it appears, are as susceptible to frost as the low-altitude Carson stock.

A few of the native Wind River trees growing near the plantations had burst their buds and were in the same stage of growth as the Carson stock, but on no native trees were signs of current frost injury noticed.

Observations in 1916 on 1- and 2-year-old seedlings of the experimental stock remaining in the nursery showed that from 90 to 100 percent of those of every seed source were damaged by severe fall frosts that occurred before the winter buds had matured, temperatures of 28°, 25°, and 26° F. being recorded on three successive nights. No significant difference in susceptibility to frost was observed among different stocks.

DEVELOPMENT OF PLANTATIONS

Aside from the findings as to comparative growth of stocks differing in provenance, this experiment affords a basis for studying the comparative annual height growth[14] of plantations, identical as to origin of stock, on lands differing in site quality. Data on annual height growth of the plantations are given in table 12.

As was stated previously, the site qualities of the plantation areas are approximately as follows: Siuslaw, II; Snoqualmie, II; Wind River, III; Mount Hood-A, IV; Mount Hood-B, V. The nursery stock was outplanted in the springs of 1915 and 1916 as 2-year transplants, in 7- by 7-foot spacing, and was measured in the autumns of 10 different years, from 1915 to 1931.

At the first measurement, in the fall of the year in which they were outplanted, the trees averaged 0.4 foot in height in every plantation. Little or no difference was found among height averages for different plantations until after the third growing season. Then the site II and site III plantings were a little taller than the site V plantings. By the end of the fifth year the site II plantings were about 2 feet tall, while the site IV and site V plantings were only about 1 foot tall. In 2 years more the site II plantings were nearly 4 feet tall, while the site IV and site V plantings were only half as tall. At the end of 10 seasons in the field, the site II plantings averaged 7 feet in height and the site IV and site V plantings were less than half as tall. At that time the site III plantings were 2 feet less in height than the site II plantings.

At the last measurement, in 1931, on sites II, III, IV, and V the heights of the 1915 series of plantings averaged 21.4, 16.9, 6.7, and 6.1 feet, respectively, and the heights of the 1916 series, with one less year's growth, averaged 18.9, 14.5, 6.4, and 4.2 feet, respectively. On a lowland area of site quality II, after 17 years in the field many trees were 35 to 40 feet tall and were 5 to 6 inches in diameter at a height of 4.5 feet above the ground. In plantations of the same age on the site V slope at 4,600 feet altitude, very few trees were more than 10 feet tall and 1.5 inches in diameter. Trees on the site II areas were more than three times as tall as those on the site V area. Considering these results from another angle, 9 seasons of growth on site II equaled 17 seasons on site V, 13 to 15 on site IV, and 11 on site III; and 8 seasons of growth on site III equaled 11 on site IV. (Between site IV and site V not much growth difference appeared until after the eleventh year. Yearly data for comparison are not available for any later period.)

The data also show the progress of stand development on ordinary wild lands in western Oregon and western Washington reforested by planting. On the site II areas the trees attained such size 17 seasons after outplanting that the stand was beginning to close and the branches at a height of 5 feet above the ground were dying. A stand in this stage of development is shown in figure 7. On the site III area, which is comparable to much of the marginal farm land now being abandoned in western Oregon and western Wash-

[14] During the first 11 years of the life of the plantations, although the plantations were not visited every year, data on annual height growth were obtained by recording, at each biennial measurement, not only the total height of the trees but annual terminal growth.

TABLE 12.—*Annual and periodic growth of plantations* [1]

Plantation area and year [2] of outplanting	Altitude	Site quality	Average height [3] at end of given number of growing seasons following outplanting: 1	2	3	4	5	6	7	8	9	10	11	16	17
	Feet		*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*
Snoqualmie: 1916	2,000	II	0.1	0.7	1.2	1.9	2.5	3.1	3.8	4.8	5.9	7.1		18.9	
Siuslaw: 1915	2,100	II	.1	.6	.9	1.5	2.3	3.0	3.8	4.7	7.6	7.1	8.6		21.4
Wind River:															
1915	1,100	III	.1	.7	1.1	1.3	1.7	2.0	2.8	3.2	4.0	5.0	6.0		16.9
1916	1,100	III	.1	.6	.9	1.1	1.1	1.9	2.4	2.6	3.6	4.4		11.3	
Mount Hood A:															
1915	2,800	IV	.1	.6	.8	1.0	1.3	1.7	1.9	2.1	2.5	3.0	3.4		6.7
1916	2,800	IV	.1	.5	.7	1.0	1.1	1.5	1.7	2.2	2.6	3.0		6.4	
Mount Hood B:															
1915	4,000	V	.1	.5	.7	.8	1.0	1.3	1.7	2.0	2.1	3.0	3.3		6.1
1916	4,000	V	.1	.5	.6	.7	.9	1.2	1.4	1.8	2.3	2.6		4.2	

[1] Stock was 2 years old when outplanted, and had been transplanted in the nursery when 1 year old.

[2] Planting was done in the spring.

[3] The averages are means of 28 averages each of which represents the progeny of a different class of seed source as determined by type of parent tree and seed-source locality. (This method has been used in the present analyses in order to utilize the results of computations made by earlier investigators with the data for the first 11 years of the experiment.)

ington, a good protective cover of 6-foot trees was obtained within 11 years. The larger trees are now closing up so that they are shedding their lower branches. Land of site qualities IV and V is producing wood volume very slowly. The test plantations on land of these site qualities required 17 years to reach a size offering material protection to watershed values.

FIGURE 7.—Section of Siuslaw plantation in 1934, 19 years after establishment

MEASUREMENTS AND GERMINATION TESTS OF SEED

When the seed for this experiment was collected, in the fall of 1912, extensive measurements and tests were made in order to discover any possible interrelations among tree type, cone yield, cone size, seed size, number of seed per cone, seed viability, and size of 1- and 2-year-old seedlings. The results have already been reported in considerable detail by Willis (*7*), Willis and Hofmann (*8*), and Kraebel (*5*), so they will merely be summarized very briefly here.

The greatest numbers of cones were produced on trees 100 to 200 years of age, or 2 to 3 feet in diameter, on land of good site quality. Such trees bore about 4 bushels of cones each. Open-grown trees produced 55 percent more cones each than dense-grown trees. The largest cones were found on the trees showing the greatest current growth of branches and shoots. On any given tree, the largest cones were found on the most vigorous branches and the smallest cones were found on slow-growing, suppressed branches. Young trees yielded larger cones than old trees. Cones from trees 15 years old averaged 700 per bushel, and cones from trees 600 years old averaged 1,916 per bushel. Large cones usually contained larger seeds and greater numbers of seeds than small cones. Seed from the largest cones averaged 35,000 per pound, and seed from the smallest averaged 57,000 per pound. Germination tests of cleaned seed showed that the number of viable seeds per bushel of cones was nearly the same for large as for small cones.

Germination tests of cleaned seed made in outdoor nursery beds during 6 successive years indicated no consistent effect of provenance upon viability of seed. Neither the form, age, site quality, condition as to infection, nor locality of the tree showed any appreciable correlation with germination of its seed. Similarly, small and large seed did not differ as to germination.

Seedlings from large seed were slightly taller at the end of the first season than seedlings from small seed, but by the end of the second season the two lots were of equal height. No other seed-source factor was found to have affected the height growth of the 2-year-old seedlings.

DISCUSSION AND APPLICATION OF RESULTS

This experiment, the first of its kind made with Douglas fir, offers evidence of what may be expected when seed of the Pacific coast form of Douglas fir from various localities is used to generate a forest in western Oregon or western Washington. The results show that if good growing conditions are provided, seed from any one of several types of parent trees will produce a fast-growing stand of young trees.

Seed trees of different ages were found to be equally good parents, so far as growth of the progeny was concerned. In an overmature stand of Douglas fir, usually there are scattered groups of young trees that are too small to be cut at a profit. Such trees will produce just as vigorous seedlings as any others in the stand. They should be left and protected as seed trees. Similarly, any old misshapen trees that would not return more than the cost of logging should be left, if they are seed producers.

Trees growing on poor sites, if they are widely spaced, are often convenient sources of seed for planting purposes. In this experiment it has been demonstrated by more than 1,000 progeny derived from the poor Lakeview site that the quality of the site where the parent grew did not affect the inherent vigor of the progeny. It is believed that the parents were from one of the first few generations developed on the Lakeview site, formerly a nonforested glacial outwash plain; possibly over a longer period hereditary deficiencies might develop as a result of poor site quality.

The differences in quantity of precipitation between most so-called "dry" and "wet" localities in western Oregon and western Washington probably are not great enough to cause the development of Douglas fir strains demanding either wet or dry sites. The tests indicate that no differential standards of moisture requirements need be assumed for Douglas fir individuals growing in different localities in the commercial timber zone of western Oregon and western Washington.

Seed trees that have grown in very dense and in very open stands produce equally vigorous progeny. Open-grown trees with wide bushy crowns produce large quantities of cones within easy access and are often the most convenient source for seed collection. There is no apparent reason why seed for planting should not be taken from isolated open-grown trees. Crowded trees, with their small crowns, do not produce so much seed as open-grown trees. From the heredity standpoint either densely grown or open-grown trees may be left to restock cut-over land; but greater numbers of densely grown trees will be required in order to produce the same amount of seed.

Of very great interest to foresters is the question whether it is safe to leave trees infected with red ring rot to perpetuate the stand. Lumbermen are willing to leave such trees, because often the wood is so permeated by rot that the tree is worthless for lumber. It has sometimes been contended that the progeny of such trees are sickly, slow-growing, and undesirable. On the other hand it has been said (*1*) that the fungus works only on the old, inactive tissue and may exercise no influence on the tree's vital functions. Heretofore no significant tests have been made to settle the question whether infected trees should be left as seed trees. In the present experiment, trees derived from parents infected with red ring rot have grown just as well as those from sound, healthy parents. At about 20 years of age, they show no signs of poor health or declining vigor.

It may be that slight inherent differences in chemical or physical structure favor the penetration of fungus hyphae in one tree more than in another. This point cannot be tested on the heredity plantations until the progeny develop heartwood, and branch-stub avenues of entry to it, under the damp shade of a crown canopy where conditions are favorable for development of red ring rot. In examining old-growth stands Boyce (*2*) found practically no red ring rot in trees less than 150 years of age; and in second-growth stands, serious rot need not be anticipated before that age. From the standpoint of managing a new stand of timber, decay after 150 years does not greatly matter; trees older than 150 years lose their earning power, and the managed forests of the future will probably be cut before they reach that age.

It is obvious that to eliminate fungus disease spores from the overmature forests of the Pacific Northwest is quite impossible, so that the leaving of conky seed trees can have no appreciable effect on forest hygiene in the region. In cutting operations, where conky trees are present and are needed for seed purposes they should be left standing, not cut and left to rot on the ground.

Restocking a forest by planting usually involves collecting seed where it is plentiful, even though the seed-supply locality is at a considerable distance from the planting site. Bringing seed from alien habitats involves chances of misfits. In a region with topographic and climatic variations as great as those of western Oregon and western Washington trees derived from the warmest part do not thrive in the coldest part, according to results in the present experiment, in which tests were made with some 11,000 trees derived from 13 different localities. Altitude serves as a convenient and roughly accurate measure of climatic differences between two localities for which actual weather records are not available, but is not entirely reliable as a gage of climate in seacoast States where climate at a given altitude differs according to proximity to the ocean. The test plantations show clearly that it is not safe to use seed from a warm coastal belt for planting in the high-mountain climate of

Oregon and Washington, and that some stock derived from high altitudes grows poorly at low altitudes. On the other hand, trees derived from certain localities at relatively low altitudes have done well at high altitudes. These more adaptable strains are very useful for planting in years when the seed crop is not heavy in all localities.

If seed is sought for planting in a locality where late spring frosts are frequent, it is unwise to collect it from a locality that does not have late frosts. Even if the source of seed is within a few miles of the planting site, cold-air drainage may cause entirely different conditions at the two places during spring nights and the seed may consequently be ill adapted to the plantation site. The problem of frost damage cannot be solved entirely by using high-altitude stock; the high-altitude stock, in response to the first warm weather of spring, may open its buds too early with the result that they are later frozen.

Bountiful seed crops of Douglas fir usually occur only once in several years. Between the heavy-seed-crop years, when satisfactory supplies of seed from some localities are not available, the planter is likely to be tempted, for example, to use coastal stock at high altitudes, or high-altitude stock in the warm climate of the seacoast. In general he cannot safely use seed until he knows its source and the climate at that source. Then he should match his seed-source area to his planting area on the basis of climate, unless he knows from actual tests that a certain seed, although native to a different climate, is suited also to that of his planting area.

One of the most important considerations in planting a forest is the possibility of selecting a strain or race of trees more vigorous than that native to the planting site. Two stocks among the 13 tested in this experiment exhibited outstanding height-growth vigor even when planted in an alien environment. These excellent strains, those of the trees from which seed was collected at Granite Falls, Wash., and Darrington, Wash., can be planted with success at any altitude in western Oregon and western Washington, from the coastal hills to 4,600 feet above sea level.

Owing to the narrow limits of the areas over which parent trees were sampled, the boundaries of the areas occupied by the superior strains are not known. This experiment proved only that stock from certain parent trees in 2 localities was better than stock from certain parent trees in 11 other localities. Unfortunately it was not possible to preserve the tested parents for later experimental use; most of them had been cut, and the identity of the remainder was lost.

If the expense of planting is justified, certainly the small extra expense required to obtain seed from especially high-quality sources is justified. Growing stock that produces 10 percent more wood than does stock from another seed source may bring extra returns 100 times the extra cost of the seed.

The mortality data taken in this experiment indicate that Douglas fir seed from any part of the commercial timber zone of western Oregon and western Washington produces trees that will survive in any other section of this territory within the range of conditions tested. Not all the stocks will grow thriftily in all such places; but in spite of influences in some localities tending to stunt their growth, all will survive.

The records of annual and periodic height growth on areas differing in site quality show that planting for wood production should be done on the best sites first. If volume growth is proportional to height growth, 1 year of idleness for a site II acre is a greater economic loss than 3 years of idleness for a site IV or site V acre.

On land of site quality II in the present zone of lumbering operations west of the Cascades in Oregon and Washington, the timber grower may expect a crop of Christmas trees in 10 years, and in 20 years or so a crop of posts and mine props.

SUMMARY

In order to test hereditary tendencies of the Pacific coast form of Douglas fir (*Pseudotsuga taxifolia* (Lambert) Britton), seed was collected in the fall of 1912 in 13 different localities in western Washington and western Oregon, within the tree's commercial range. The trees from which seed was collected, numbering in all 120, were so chosen that in most of the 13 localities they afforded contrast in individual characteristics. Comparable collections were made from younger and older trees, from trees growing on areas of good site quality and poor site quality, from open-grown and crowded trees, from fungus-infected and uninfected trees, and from trees at high and low altitudes.

Cones and seed were measured, and seed was tested for germination. The seed was sown in nursery beds in the springs of 1913 and 1914. The trees grown from it were transplanted within the nursery at the age of 1 year and were used in the springs of 1915 and 1916, at the age of 2 years, to establish replicative test plantations each containing progeny of every parent tree. These plantations were located on burned-over, uncultivated forest land, in four localities and at four different altitudes. All the test-plantation areas, like the seed-collection areas, were within the principal range of the Pacific coast form of Douglas fir. The planted trees were observed and measured in 10 different years, from 1915 to 1931. In the latter year the surviving progeny numbered about 8,500 on four 1915 plantations and about 2,800 on four 1916 plantations. Findings were as follows:

The age of the parent tree, the quality of its growing site, its growing space, and its condition as to fungus infection had no effect upon the height growth of the progeny.

One stock from a high altitude made much less growth than the average of all stocks in the equable climate of the Oregon coastal hills, but grew much better than the average at a high altitude in the Cascade Range. In contrast, a stock from the Oregon coastal hills made less growth than the average of all stocks in the high-altitude plantation, but grew much better than the average in the coastal plantation. Several stocks grew equally well, in comparison with the average, on each of the five plantation areas.

Progeny from two seed-source localities made outstandingly good height growth. On every plantation area they exceeded the height-growth average for all stocks. Since no characteristic of the parent trees as individuals was found to explain it, this outstanding growth was attributed to inheritable vigor characteristic of a strain or race within the variety.

Little difference was observed between the average height growth of the progeny of a given tree and the average height growth of the progeny of all parent trees in the same locality.

Mortality in the plantations was not affected by source of seed.

Marked differences in the dates at which progeny from seed trees in different localities burst their leaf buds were observed in the Wind River and Mount Hood plantations in the springs of 1933 and 1934. In 1934, a year when the growing season began about 1 month earlier than in 1933, the order in which the various stocks burst their buds in the Wind River plantations was nearly the same as in 1933.

One of the stocks that burst their buds early in the season on the Wind River area was badly frozen in the spring of 1933 during a single night when the temperature fell to 29° F., after a series of relatively warm days and nights. This stock had been frozen in previous years, also. Another stock on this area that had opened its buds was not affected by the frost.

Trees on plantation areas of site quality II grew as tall in 9 years as trees from the same parents on a plantation area of site quality V grew in 17 years. On a good-quality lowland site, after 17 years in the field many trees were 35 to 40 feet tall and were 5 to 6 inches in diameter at a height of 4.5 feet above the ground. In plantations of the same age on a poor, rocky slope at 4,600 feet altitude, very few trees were more than 10 feet tall and 1.5 inches in diameter.

No parent characteristics were observed to have affected significantly the viability of the seed. The largest cones and seed were found on the young trees and on the most vigorous branches of any given tree. Seedlings from large seed were slightly taller during the first year than seedlings from small seed, but during the second year the difference disappeared.

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