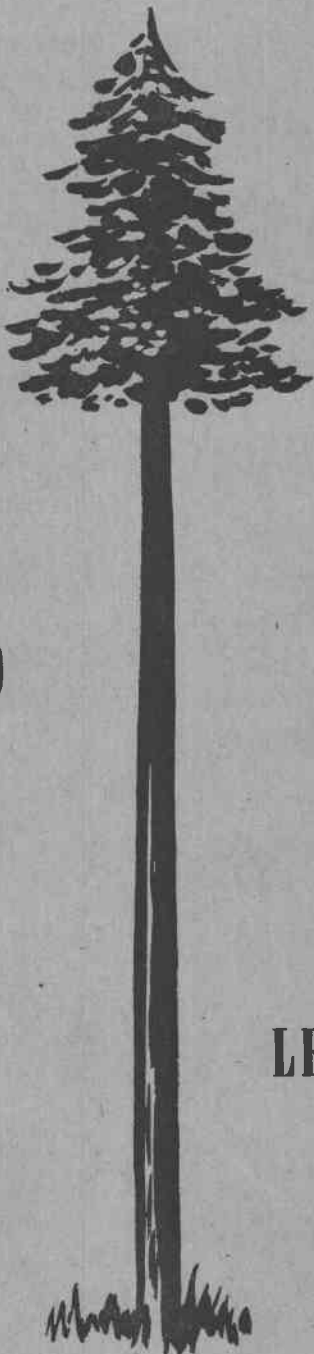
E. F. Peffer

BETTER DOUGLAS FIR FORESTS *from* BETTER SEED



LEO A. ISAAC

Compliments of the author to Al Peffer, fellow forester and esteemed friend.

Leo A Isaac 9/1/56

A Road Through the Douglas Fir Forest of Tomorrow

An even-aged young-growth stand that followed early-day clear-cutting. This stand, 20 to 25 years old, is typical of many that followed cutting when successive fires were kept out.

(Photo, courtesy West Coast Lumbermen's Association)

Agnes H. Anderson Research Publications

Better Douglas Fir Forests from Better Seed

Better Douglas Fir Forests From Better Seed

By

LEO A. ISAAC

SILVICULTURIST

College of Forestry, University of Washington

and

Pacific Northwest Forest and Range Experiment Station

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Foreword

Within the past decade, there has been a decided change in the attitude of the Pacific Northwest timberland owners toward the handling of their forest lands. At the beginning of the decade the average operator was concerned only with getting out logs and little or no thought was given to the condition of the land or to the future timber supplies. During this period, however, there has been a growing interest in better forest practices. The first evidence of this changing attitude was the development of the "Keep Green" movement in Washington and later in Oregon. This was followed by the "Tree Farm" movement, which started in the Puget Sound area and spread throughout the region, and both of these programs have since become popular throughout the nation.

Along with these developments a few of the larger companies began to take stock of their assets and to look toward planting some of their nonreforesting lands. In a few cases, wild stock was planted, as seedlings from commercial nurseries were not available. This was followed in several instances by the development of company nurseries. As interest grew and the magnitude of the problem became apparent, industry pooled its efforts to establish an "Industry Nursery" at Nisqually, Washington. This nursery, with a capacity of eight or ten million trees, grows seedlings on consignment for the operators in the Douglas fir region of Washington and Oregon. Its operation was successful from the start and the production has increased annually. The states have stepped up their nursery programs and farmers, through the leadership of the Soil Conservation Service, have also become interested in planting, although on a minor scale.

With this interest in planting has come an increased demand for Douglas fir seed. Although there was plenty of information on the results obtained when poor seed was used with other species in other regions, the application to our Douglas fir forests was not readily available. Unfortunately, there has been little or no information available on proper Douglas fir seed sources or the consequences of gathering seed from improper sources.

As the outcome of using improper seed cannot be determined for several decades, the resulting economic loss increases as the years pass. When we add to this the vastness of the reforesting problem in the Douglas fir region, totaling some three million acres, the importance of proper seed source becomes increasingly apparent.

As the proper management of these lands is extremely important to the future welfare of our state, the University, in 1945, through the Agnes Healy Anderson Research Fund, authorized the College of Forestry to undertake a study of proper Douglas fir seed sources. In seeking someone to do the work, Leo Isaac, Silviculturist of the Pacific Northwest Forest and Range Experiment Station of the U. S. Forest Service, stood above all others because of his broad knowledge of Douglas fir silviculture. The cooperation of the U. S. Forest Service was requested, and they agreed to grant him a six months' leave of absence to carry on research in this field at the University.

The results of this study are contained in the following pages. They are not the results of original research but rather of bringing together all available information pertaining to the problem. The author has expressed some new thoughts and ideas as well as bringing new emphasis in certain areas and pointing out needed research in others. We hope this publication will fill a need and will be widely used by those interested in the management of Douglas fir forests and that as a result we may get *Better Douglas Fir Forests From Better Seed.*

GORDON D. MARCKWORTH
Dean, College of Forestry
University of Washington

CONTENTS

ILLUSTRATIONS

Fig. 1—Vast areas in the Douglas fir region have been swept clean by clear-cutting and fires. Many of these areas are close to seed sources and will restock, but some are not and will have to be planted. Areas like the background of this picture go to make up the millions of acres of unsatisfactorily stocked land in the Douglas fir region.

Fig. 2—Douglas Fir Under Management

This is a 66-year-old stand in Denmark. It has 68 trees per acre, an average d.b.h. of 19.8 inches and an average total height of 110 feet. The total basal area is 165 square feet and volume per acre is 7,379 cubic feet; but there have been many improvement cuttings, for the mean annual increment is 257 cubic feet per acre. According to Douglas fir site classification an average height of 110 feet for trees which are all dominants and codominants would place the area in site class III. With an annual increment of 257 cubic feet, more than remains in the stand must have already been harvested. Danish foresters are producing under management more total cubic-foot volume on site III than is found in natural unthinned stands on site I in the Pacific Northwest.

Introduction

The forest industry is by far the greatest industry in the Northwest. It has brought about, directly or indirectly, more than half of the total income in the Douglas fir region of Washington and Oregon. Furthermore, much of the land in the Douglas fir region is chiefly valuable for growing of forests and can be used profitably for nothing else. Some of it embodies the finest timber-growing land and climate in all America.

Roughly two-thirds of the forest area of western Washington and one-third of western Oregon has been cut over or burned. Over five million acres of these deforested lands are now listed as either nonstocked or unsatisfactorily stocked with seedlings or young growth (62).* About two million acres of this were cut over since 1930, half of which will probably restock naturally. That leaves about four million acres that will not restock (Fig. 1), for about a million acres have already remained treeless since prior to 1920. It is estimated that a million acres are not plantable because of rocky surface, excessive brush, etc.; that leaves, in round figures, three million acres in need of planting in the Douglas fir region.

Private companies and public agencies have had reforestation programs under way, but the total acreage of artificial reforestation by all agencies in the Northwest by 1946 was just about 150,000 acres.

Those figures—3,000,000 acres in need of planting, 150,000 planted—illustrate the magnitude of the problem confronting the foresters and timberland owners of the region if this land is to be restored to full productivity. This vast rehabilitation job also illustrates the wisdom of a study of the problems of raising Douglas fir forests from seed and a study of how such tree crops may be improved under management.

Forestry is the last great industry whose raw material consists of living things that has not materially improved the original wild stock under management. The reason is threefold: not all forests are under management and some under management have not been there long enough for improvement to come about; satisfactory raw material can still be drawn from wild or natural stands; and it takes more years for timber trees to flower and to produce a crop than most plants, and thus more years to bring about improvement.

Vast improvements in hardiness, per-unit yield, and quality of product have been made for grains, grasses, fruit trees, and other growing things that contribute to man's welfare. These improvements are well known.

* Numbers in parentheses refer to literature cited, p. 64.

They are mentioned here only for contrast with forest trees, about which little has been done toward improvement—and very little of that improvement has been put into practice.

World-famous Washington apples are a far cry from their direct ancestor, the wild crabapple. But the Douglas fir (*Pseudotsuga taxifolia, Britt.*) in Washington plantations shows no improvement over its parents in the virgin stand, and often may not be as good. Should the forest industry be content to stand still or should it strive to keep pace with other industries and improve its growing stock? The answer is obvious.

Why Grow Douglas Fir?

"Why grow Douglas fir?" is a legitimate question often asked by foresters and timberland owners in the Pacific Northwest. The answer is simply this—over a considerable portion of its optimum range west of the Cascade Mountains the Douglas fir is far superior to other trees. The proof lies in the published growth and yield tables (42), in the thousands of acres of young-growth stands in the field, and in the experience of foresters who have raised Douglas fir to harvest age in plantations (Fig. 2). Kanzow (33), who has summarized the growing of Douglas fir in Europe, has this to say: "According to results obtained from the experimental plots it seems justified to increase the area of planting of the green Douglas fir (that from western Washington and Oregon) in Germany, because this species produces more wood per unit of area than any native tree, and the quality and utility of the wood for milling or construction purposes, or in the form of poles, is satisfactory. As a half-shade species producing useful wood, the Douglas fir fills a gap long existent in regard to species for the better, grass-covered soil of the pine belt."

In discussing the selection of species for planting, Heiberg (29) stated: "In Great Britain it costs two to four times more to produce one cubic foot of Scotch pine or European larch than one cubic foot of Douglas fir."

In the fog belt along the Oregon and Washington coast, records (44) show that the yield from western hemlock (*Tsuga heterophylla, Sarg.*) and Sitka spruce (*Picea sitchensis, Corr.*) is greater than the yield of Douglas fir (*Pseudotsuga taxifolia*). At the higher elevations Douglas fir is sometimes replaced by a better forest of noble fir (*Abies procera, Lind.*) and silver fir (*Abies amabilis, Forb.*). But on the well-drained sites inland from the coast and at middle elevations in most of the interior valleys west of the Cascade summit, Douglas fir is found to be by far the most superior tree in all respects, and it is probably the easiest to handle under management.

from Better Seed

Why Strive for Better Douglas Fir Seed, Better Trees, and Better Stands?

Natural Douglas fir stands are good but improved stands are likely to be more profitable. Also, if care is not taken to secure the best stock for reproduction, future stands are likely to be poorer instead of better than the natural stands.

Any business or profession, to thrive or survive, must show a net profit or gain, and this certainly is true of forestry, particularly private forestry. Extreme care in the starting of forest crops is more essential and profitable than with other crops. This can be shown in dollars and cents.

Mistakes in the selection of seed, or growing stock, or in procedure can be corrected from year to year in short rotation crops, but in forestry mistakes usually cannot even be detected for a number of years. Such mistakes ordinarily cannot be corrected until the end of the forest rotation, which may be anywhere from 50 to 150 years in the Douglas fir region.

Many tables have been prepared and are available in textbooks and handbooks showing costs of growing timber in America. They are based primarily on rates of growth of natural stands. *West Coast Tree Farms* (65) table shows Douglas fir growing costs up to 80 years of age for all sites, starting (a) with bare land and planting 500 seedlings per acre, (b) with a one-year-old stand of natural seedlings, and (c) with a 20-year-old stand of natural young growth.

Table 1, taken from the above-mentioned table, shows the cost of growing timber on site II Douglas fir land only. This simplified table is for a slightly better than average site for the region as a whole. It will serve to show why it is worth while to strive for better Douglas fir. Costs per unit of volume produced will be lower on better sites and higher on the poorer sites. Although the general tables (65) use the same costs for all sites there are some compensating factors that tend to equalize costs with production. As a rule when site values go from the better to the poorer, land values or rent, taxes, and interest also go down slightly, though not in the same proportion. Planting and protection costs do not change. Then, too, natural restocking becomes progressively more prompt and adequate as sites get poorer, except where sites are so severe that seedlings cannot become established.

The compilations in Table 1 are based on a single cut at rotation age. Any gains that may come about through pruning, thinnings, stand improvement, or a prolonged rotation, will be over and above those shown in the table. Demand and market figures since World War II indicate that cultural operations will pay and that there will be a market for material that until now was below merchantable size.

Table 1—*Cost of growing Douglas fir timber on site II land*

Age	Initial Outlay Per Acre		Annual Outlay Per Acre		Total Cost Per Acre		Average Site II	
	Planting $9.00	Fire Development $1.00	Annual Fire Protection $.15	Rent $.03 Taxes .04 Admin. .05 Total $.12	Actual Amount Spent	Amount Spent Plus 3% Interest	Yield in Bd. Ft. Per A.*	Total Cost per M Bd. Ft.
Years	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Dollars*	*Dollars*		*Dollars*
Bare land with 500 planted trees per acre								
1	88	10	1	1	10.27	10.27	....	....
10	74	8	10	8	12.70	16.50	....	....
20	64	7	16	13	15.40	25.36	....	....
30	59	7	19	15	18.10	37.13	3,100	11.90
40	56	6	21	17	20.80	52.96	13,000	4.07
50	53	6	23	18	23.50	74.25	27,500	2.70
60	51	6	24	19	26.20	102.92	41,000	2.51
70	50	6	24	20	28.90	141.52	51,700	2.74
80	49	6	25	20	31.60	193.17	59,900	3.22
Land satisfactorily stocked with one-year-old natural young growth								
30	....	16	47	37	9.10	15.26	3,100	4.92
40	....	14	48	38	11.80	23.62	13,000	1.82
50	....	12	49	39	14.50	34.83	27,500	1.26
60	....	12	49	39	17.20	49.91	41,000	1.22
70	....	11	50	39	19.90	70.24	51,700	1.36
80	....	11	50	39	22.60	97.41	59,900	1.63
Land satisfactorily stocked with 20-year-old natural young growth								
30	....	30	39	31	3.70	4.44	3,100	1.43
40	....	20	44	36	6.40	9.07	13,000	.70
50	....	16	47	37	9.10	15.26	27,500	.56
60	....	14	48	38	11.80	23.62	41,000	.58
70	....	13	49	38	14.50	34.83	51,700	.67
80	....	12	49	39	17.20	49.91	59,900	.83

* Note: Yields from U.S.D.A. Tech. Bul. 201. The estimates include trees 12″ d.b.h. and over in 16′ logs to 8″ top by International Rule (1/8″ saw kerf).
Yields were reduced about 15 percent to compensate for understocking and loss from fire, insects, and disease. Other figures taken from *West Coast Tree Farms* (65).

from Better Seed

The table shows that site II land will produce about 40M feet per acre on a 60-year rotation at a total cost of $2.50 per M feet, including 3 percent compound interest. If the owner sells his stumpage at (cost) $2.50 per M feet, he has made 3 percent compound interest on his investment. If the stumpage is sold at $3.00 per M, there will be, in addition to the 3 percent compound interest, a final net profit of 20 percent over cost of production. The table is based on 1943 prices; since then both costs and stumpage rates have risen proportionally.

The total cost of planting and the subsequent carrying charge is just as great on a poor tree or a poor stand per acre as it is on a good tree or a good stand per acre; that is a well-established fact. The figures in the table are based on the average tree in existing natural stands. Therefore, if it is possible to increase the final yield 20 percent (and that is not at all out of reason), it will raise the additional net profit from 20 to 44 percent, or an increase in net profits of 120 percent over that of a normal stand.

On the other hand, if the yield from the planting is 20 percent below normal, losses will be proportional, because production costs will remain essentially the same. In this particular instance the operation would show a loss of 4 percent instead of a net profit of 20 percent as shown for the normal stand. In other words, the forest industry, with fixed production costs, shows clear gain for any increase in final yield or a clear loss for any decrease in final yield. From these simple figures it is evident that it is worth while to strive for better stands.

For the purpose of contrast there is presented in simplified form in Table 2 calculated returns from site II Sitka spruce-western hemlock planting based on 1947 cost levels. These costs were prepared by a private forester for a company contemplating the reforestation of site II lands in Oregon. With a general increase in costs of growing and a consequent increase in stumpage price there is all the more reason to strive for better stock that will produce higher yields. For all volume above normal there is a greater increase in final returns because of the increased stumpage price. In this instance there would be a $10.00 per acre increase in net returns for each thousand board feet produced above normal yield.

What Are the Chances for Improvement in Douglas Fir Forests?

Douglas fir trees and stands can be improved. Superior trees and superior timber crops occur for two reasons: (a) a better strain of growing stock, either natural or developed; and (b) favorable growing conditions. Either a better strain of growing stock or exceptionally good growing con-

Table 2—*Returns from planting on site II Sitka spruce-western hemlock land* (70-year rotation)*

Investments plus compound interest at 3%		
Cutover land value per acre	$ 5.00	Total $ 40.00
Planting costs per acre	20.00	Total 160.00
Taxes†—12½% yield tax. Ore. Reforestation Law		Total 68.75
.05 per acre per year land tax (70 yrs.)	3.50	Total 11.53
Fire protection, improvements, & administration at .75 per acre per year (70 yrs.)	52.50	Total 172.95
Total investment per acre		453.23
Returns‡—55 M feet at $10.00 per M		550.00
Margin of return over costs plus 3% compound interest		96.77

* Computed by H. E. Haefner, April 9, 1948.

† Tax computed under Oregon Reforestation Law on the basis of a final yield of 55 M feet per acre and an estimated stumpage value of $10.00 per M.

‡ U.S.D.A. Bul. 544 shows a normal yield of 68.5 M feet per acre for site II Sitka spruce-western hemlock at age 70 years. The figure of 55 M feet per acre was set in this computation to allow a safe margin for losses from fire, insects, and disease. In addition to the amount shown above a substantial return should be realized from thinning and stand-improvement cuttings.

ditions will tend to improve a forest stand, but when the two occur in combination the ultimate in final yield can be expected.

The first step toward a better and more profitable crop of Douglas fir under management is to secure the very best natural strain of seed for each individual reforestation area—considering both climate and soil. Ways and means of accomplishing this end, plus some general and some specific information that will be of immediate assistance in the practice of growing Douglas fir, will constitute most of the subject matter of this publication.

The second step, by its nature, must come over a long period of years. This is the gradual improvement of the species (in growth rate, hardiness, and quality) through selection, hybridization, change in number of chromosomes, or use of growth hormones.

It is uncertain to predict but fascinating to speculate as to what might happen when once the work of improving the species really gets under way. There are positive gains that can be made through selection and crossbreeding. There are less certain but more astounding possibilities in the realm of change of chromosome numbers and in the use of growth hormones.

What is Known About the Douglas Fir Family

It has been proved beyond a doubt both in this country and abroad that in natural stands strains of a tree species (including Douglas fir) exist that are superior to others in quality or hardiness or rate of growth, just the same as there are superior strains of other growing things. It has also been proved that strains of a species (again including Douglas fir) have specific environmental requirements (climate and soil) that are necessary for the best, or even satisfactory, development. If further proof of these statements is needed it will follow, but first let us determine just how much is known about the genus and the conditions under which this tree grows.

Douglas fir was first discovered (24) (28) on the Pacific Coast by Archibald Menzies on Vancouver Island in 1792 on a voyage with Captain Vancouver. It was first described and named *Pinus taxifolia* by the Scotch botanist, Aylmer Bourke Lambert, in 1803. He was a fellow worker and close friend of David Douglas, another Scotch botanist, who worked out from McLoughlin's Hudson's Bay Company post at Vancouver, Washington. Douglas sent the first seed to England in 1826 and 1827 and in his honor the name "Douglas fir" was given to the tree. The scientific name given it by Lambert had already been given to another tree, so Douglas fir was again described by Jean L. M. Poiret, a French botanist, in 1804 and called *Abies taxifolia.* In 1867, Carriere separated it into a new genus and called it neither *Pinus* nor *Abies* but *Pseudotsuga douglasii.* For a time Sudworth called it *Pseudotsuga mucronata,* then in 1899 Britton proposed the name *Pseudotsuga taxifolia*—the scientific name it has retained to date.

Since the tree is neither hemlock, spruce, yew, nor fir, as its scientific and common names might indicate, the common name, Douglas fir, adds to the confusion. It would rob the tree or the name of none of its significance and eliminate a great deal of future confusion in nomenclature if the word "fir" were dropped from the name and the tree were simply called "Douglas" as is now being done in European countries (*Douglasii* or Douglas).

Since its discovery different scientists and research workers have studied various phases of the life history of the *Pseudotsuga.* A great deal of the essential knowledge is at hand, but the study is as yet very far from complete.

This genus is found in natural stands only in western North America and eastern Asia. The subdivision of the genus is still a matter of uncertainty. Four commonly recognized species as listed in *Standardized Plant Names* (5) are:

> *Pseudotsuga japonica* or Japanese Douglas fir
> *Pseudotsuga sinensis* or Chinese Douglas fir
> *Pseudotsuga macrocarpa* or big-cone Douglas fir (California)
> *Pseudotsuga taxifolia* or (common) Douglas fir

Only the latter of these four is of great commercial or economic importance. Its range is from Mexico northward into Canada and eastward to eastern Montana and Colorado. As the drier limits of its range are approached it occurs only on the more moist sites.

Within the species Douglas fir (*Pseudotsuga taxifolia*), many botanists and foresters recognize three separate varieties. They are: the *caesia* (or gray form) from the intermountain and northern part of the range; the *glauca* (or blue form) from the Rocky Mountain and southern part of the range; and the *viridis* (or green form) from the Pacific coast.

The mountain forms are for the most part slow-growing. They are of interest outside of their own range only for tree breeding and for use in parts of the country where a more hardy tree is required because of severe climatic conditions. In a general way, the *glauca* (or blue form) appears to be associated with the interior and southern Rocky Mountain dry belt of the range; the *caesia* (or gray form) is chiefly confined to the interior somewhat moist belt in the central and northern part of the range; and the *viridis* (or green form) is associated with the moist coast zone. In the transition zones the individuals of the three varieties are so similar that it is difficult to tell them apart. Also within any one of the varieties there are individuals with a wide difference of foliage color. The coast (or green) variety is the fast-growing strain that has received attention and favor in reforestation programs in this country and abroad. It will receive most attention in this report.

Flowering and Seed Formation

The life process for Douglas fir (the flowering and seed formation) starts in September when the pistillate (female) and staminate (male) flower buds start formation. Both are very inconspicuous until they start growth the following spring. The female cell developes under the scales of the tiny conelet in the pistillate flower, the male cell or sperm is produced by the pollen that developes in the staminate flower. Both flowers occur on the same tree, in fact on the same twig (Fig. 4), the pistillate flowers occurring just below the terminal bud and staminate flowers farther down on the current year's growth.

The pollination and fertilization process of Douglas fir is not completely known. Allen (3) working in British Columbia considers the tree practically self sterile. It is not known if this is true in all parts of the range. He found that ovules of a given tree are almost never fertilized by sperms from pollen produced by the same tree, because the male and female flowers on the same tree (or twig) open at different dates. When the female flower opens it receives pollen from the male flowers of adjoining trees that are already open, when the male flower matures it in turn pollinates female flowers that are open on other trees. This variation in flower opening is a provision in nature that promotes cross-pollination between trees in a stand.

In the middle of the range of the coast form the male and female flowers (or reproductive buds) burst in early April; pollination takes place over about a one-week period for the individual tree but there is sufficient variation between trees to extend the period to three weeks for a stand. After pollen dissemination the male flower withers and disappears, but the female flower or conelet, if successfully pollinated continues to develop into a mature cone with two seeds under each cone scale. Flowers are not always abundant particularly after years of heavy seed production. But if they are plentiful, weather conditions during the pollination period determine the development of a seed crop. Excessive or continuous rain or hard frosts at that period might prevent successful pollination and hence the formation of a season's seed crop. Although pollination takes place in early April, actual fertilization of the egg cell contained in the developing seed does not occur until early June (1); if not successfully pollinated or fertilized the conelet, like the male flower, withers and disappears.

The conelets, which are at first erect, turn downward as they grow and finally develop into the well-known pendant cones. Both the cones and the seeds in them are full grown by the end of July. They are ripe and ready to start seed dissemination by the end of August. All dates are slightly earlier for warm sites at lower elevations and slightly later for cold sites at higher elevations. The mature cones closed and open, and seeds with and without wings are shown in Fig. 5.

Seed Viability and Germination Tests

A thorough machine cleaning of Douglas fir seed will result in a high percentage of full or sound seed in a lot. Normally most of such seed will germinate but not all seed that will germinate between moist blotters will have sufficient vitality to produce seedlings; the loss may run to as much as 15 percent. The percent of seed that will produce seedlings when planted in moist soil is the significant figure to the forester and will constitute the measure of viability when referred to in this report.

The "cutting test" is the only test that will give the seed collector, nursery man, or forester an immediate measure of seed viability. It consists of cutting in cross section with a razor blade or sharp knife 100 to 300 seeds (depending on accuracy required) and tallying the seeds that are sound and not sound. If the meat is full and not discolored, the seed is reasonably certain to be viable and is tallied as sound. The "percent sound" will consistently be higher than the percent that will produce seedlings and even a few percent higher than will germinate between moist blotters. But when this adjustment is made the test is otherwise fairly reliable if the seed has not been injured by overheating or some other abnormal treatment.

The "cutting test" can even be used to determine quality of cone crop at the time of ripening. The cones are cut in cross sections with a sharp hatchet or other blade. First it is estimated what percent of the seed completed development in the cone, then the cut seed is tallied as sound or not sound and the germination percent computed (Fig. 5).

The next measure of viability available is an actual germination test, either between moist blotters or in moist soil. Both of these tests require a period of after-ripening for two or more months before an accurate determination of viability can be made. For a quick and accurate germination test of Douglas fir, Allen (4) suggests that the seed be stratified in moist sand at a temperature just above freezing for a period of 6 to 8 weeks; then washed, sterilized, washed again, and a germination test made on sterilized moist sand in a humid atmosphere at a temperature of about 68° F. A complete and accurate germination test can be made in about 12 days after the stratified seed is washed; but the percentage of germination obtained, like that obtained between moist blotters, will be slightly above the percentage that will actually produce seedlings in moist soil.

At Boyce-Thompson Institute (22) a rapid method of determining germinative capacity of dormant seeds is being used regularly for testing forest tree seeds. The method consists of removing the embryos from seeds and placing them on moist filter paper at room temperature for immediate germination. Dr. Flemion (22) states: "By the method described in this article viability can be determined within three to ten days in very dormant seeds and within a very short time in the case of quick-germinating seeds." Also: "The percentage viable as well as some indication of vigor (probability of seedling production) is obtainable."

Embryos of Douglas fir and the pines are soft and easily injured. Skill, care, and patience are required for their excision. The seed is first soaked in water for 24 hours or placed in moist peat moss at a temperature just above freezing for a period of five days. Then the outer seed coats are removed and slits are made in the naked endosperm with a razor blade or other sharp instrument. After another short period of soaking the endosperm can be spread and the embryo floated out and placed on filter paper with a camel's-hair brush. Placed on moist filter paper in a petri dish and held at room temperature, the embryo should show complete germination in a period of five to ten days. If the seed was viable the embryo will grow and the cotyledons will spread apart and turn to a yellow-green color. If the seed was not viable the embryo will turn to a darker color and shrivel up. This new method of rapid determination of viability can be used at any time after seed is extracted and thoroughly air-dried. It is particularly valuable in determining the amount of seed to acquire for the production of a specified number of seedlings or whenever there is not sufficient time for the ordinary germination test to be made.

Reproduction—Natural and Artificial

Starting with the seed the reproductive habits of Douglas fir have been thoroughly covered by other publications (30) (36); therefore, only certain significant points that have a definite bearing on improving the crop by the production of superior stands will be covered in this publication.

The best growing sites or trees are often not the most abundant seed producers; in fact, the reverse is more often true. Furthermore, although Douglas fir is considered an adequate seed producer, it is by no means a continuous seed producer. Records show a heavy crop at five- to seven-year intervals with about one complete crop failure and two or three each of light and medium crops intervening. A crop may be more or less general or it may be concentrated in certain localities; also, there are occasional years when young trees produce best. Therefore, it is highly essential that foresters and seed collectors provide adequate cold storage facilities for seed in order that they may take advantage of heavy crops when they occur on desirable areas, and hold the seed in storage for use during years of lean seed crops.

Trees can be made to produce more seed by girdling, root shock, banding, and similar methods; however, these measures are as yet very costly and if done continuously may result in some permanent injury to the tree. Soil fertilization also appears to offer some promise. It has been found less expensive and more satisfactory to collect a surplus of seed during years of heavy crop and hold it in cold storage for the lean years.

Seed Storage. It has been shown by tests that if proper procedures are followed, seed of Douglas fir (also of the other commercially important species) can be held in cold storage for a period of five to ten years without appreciable loss of viability.

Many and weird are the methods tried to store tree seed. But after a careful review it appears that ordinary thorough air-drying, followed by cold storage, is the most satisfactory method for keeping seed of Douglas fir (and associate species). This method is satisfactory for all ordinary commercial purposes. A simple drying procedure is to spread seed out in thin layers and allow it to dry for a period of two weeks in a warm, dry atmosphere. Artificial dessication by various means has been found harmful. In storage, seed keeps well in a dark, dry atmosphere at temperatures of 40°F down to 32°F. But it keeps better below freezing and has not been injured by temperatures as low as zero. Sealing in tight containers after drying appears to help, but is not essential in cold storage. When storage is at room temperature, however, sealing is extremely helpful and vacuum seal appears to be even more so.

Subjecting intact seeds to a period of low temperature brings about conditions which make for vigorous growth (22). If seed has been stored at temperatures below freezing, it is well to hold the seed in moist air just above freezing (up to 40°F) for several weeks before planting. During this period, moist granulated peat moss or moist sand should be mixed with the seed if it will not interfere with the planting operation, or be too difficult to separate before planting. If seed has been stored dry and after storage is not mixed with a moist medium, it should be thoroughly soaked before planting.

These recommendations are substantiated in a measure by studies made at Boyce-Thompson Institute by Dr. Lela V. Barton (12). During 1946 the Pacific Northwest Forest and Range Experiment Station sent her seeds of all important northwest species. She has studies under way to determine the most satisfactory temperature at which each should be stored. Preliminary information may be available by 1950, but final results will not be obtained until 10 years have elapsed.

Seed Dissemination and Seedling Establishment. Although Douglas fir and other seed may be held for a number of years under proper storage conditions, its natural life after ripening and falling in the forest is short, usually not extending beyond the succeeding summer germination period. Seedfall at the lower elevations starts in late August and is almost over by November 1, but cool sites and continuous moist weather may extend the period well through the winter. Wind is the chief disseminator of seed of Douglas fir and its associates. Normally seed will be disseminated in sufficient density for restocking to a distance of a quarter mile out from an edge of old-growth timber. The density of seedfall varies inversely with the distance from the seed source. But abnormal air movement, such as rising or falling air currents, frequently results in a shorter distance or a much greater distance of seed flight.

The heavy loss of seed through consumption by small mammals (45) and the heavy loss of first-year seedlings are well-known facts, but past publications have not given enough attention to the significance of shade in the establishment of seedlings. After germination the seedling requires some shade for survival during the first year on all except the most favorable exposures. The shade may come from debris, lesser vegetation, or overwood. Once established the seedling makes magnificent growth in full sunlight. Kanzow (33), speaking of Douglas fir in Europe, calls it a half-shade species yet does not mention growing it under the "shelterwood" or "selection" systems of cutting. It will reproduce under an overwood that provides about half shade if ground conditions are favorable. In the Douglas fir region west of the Cascade Range, however, the seedlings do not become well established or make normal growth if the overwood consists of large, old trees. Seedlings simply cannot compete with old trees for soil nutrients and moisture during the hot, dry summers that prevail in the region.

In a controlled test (made by the author), with no root competition from overwood, two-year-old nursery-grown seedlings made better survival and growth under 20 percent of full sunlight than they did in the open during the first two years, but during the next five years their growth decreased until they were practically at a standstill. Some seed was planted at the same time the nursery-grown seedlings were put in, and all seedlings that germinated in place under the 20 percent of full sunlight died within two years.

In field plantations seedlings planted in full sunlight usually survive, but those planted in some shade usually get a quicker and better start. The points to remember are these: the species requires some shade during the seedling stage and will tolerate light shade in later years if there is not too much root competition; once started the species thrives best and grows faster under full light in even-aged stands. (Some strains may be more shade and drought resistant than others, but this will be discussed in the chapter on introduction of superior strains and elsewhere in the report.)

Chemical Aids for Rooting Cuttings. Down through the ages, many plants have been propagated from cuttings. In recent years this technique has been given impetus through the use of chemicals to stimulate rooting.

In any program of genetic improvement of a species, it may be necessary to preserve or perpetuate the stock of a single clone or parent tree. In such programs the use of chemicals to stimulate the rooting of cuttings is certain to play an important part. The rapid production of stock from selected parents for the development of seed areas and for the production of parent stock for forest genetics work are other examples of work in which forced rooting will find favor. In its present form the technique is a useful tool in genetics. There is also great hope that less costly procedures will be developed that will enable the process to be used in general reforestation programs.

Many persons have worked in the field of root-inducing chemicals and many substances have been tried. A few of these will illustrate the work done with coniferous forest trees.

Henry Kirkpatrick at Boyce-Thompson Institute states (35): "Reports from other sources and results of our own work have shown that indolebutyric acid is definitely the best root-inducing substance to date for most varieties in the commercial field." He used it in solution and powdered form on evergreen cuttings. Best rooting occurred under temperature range of 60°F to 75°F, and night temperatures below 60°F resulted in failure. Small twigs pulled from the stem rooted more readily than twigs cut from a stem. He rooted several varieties of *Abies*, *Chamaecyparis*, *Juniperus*, *Pinus*, *Picea*, *Taxus*, *Thuja*, and *Tsuga*. In his work all these genera responded well except *Pinus*.

Other workers in Australia (31) found that Monterey pine (*P. radiata D. Don.*) produced satisfactory stock from cuttings. Also Dorman (7) at Lake City, Florida, produced rooted cuttings of slash pine (*P. caribaea, Morelet*) for naval stores plantations.

Griffith (25) at the University of British Columbia used indolebutyric acid, indoleacetic acid, and alpha naphthalene-acetic acid on dormant cuttings of Sitka spruce and Douglas fir. He concludes: "Dormant cuttings of Douglas fir and Sitka spruce can be successfully rooted to the extent of 80 and 100 percent respectively by treating with either indoleacetic acid or indolebutyric acid." Indolebutyric acid was best. When used in a 24-hour treatment, a solution of 50 parts per million was found most satisfactory for Douglas fir, and 25 p.p.m. was found most satisfactory for Sitka spruce.

Dr. W. F. McCulloch[1], working with Douglas fir at Oregon State College, found the roots of chemically treated cuttings less rugged than those of normal seedlings grown from seed. He also found that eight years after outplanting the rooted cuttings did not exhibit the straight-stemmed

[1] McCulloch, W. F. Unpublished file records. Corvallis, Oregon, 1947.

characteristics of normal young seedlings but remained misshapen and dwarfed.

The rooting of Douglas fir by use of root-inducing substances has been accomplished experimentally; with some other species the process is sufficiently successful to produce stock for reforestation. A simpler, less expensive, and more successful process is necessary, however, for Douglas fir before it can be put to general use in reforestation programs.

Grading or Culling of Nursery Stock. After obtaining the best seed available, eliminating inferior seedlings in the nursery provides another opportunity to improve the stand under management.

In a well-ordered nursery where seedlings are not crowded and are uniformly watered and fertilized, the comparative size and condition of seedlings are positive measures of plant vigor. Much can be gained by culling out trees of poor vigor, bad form, or poor root development, as well as trees that have been injured in any way. This does not hold true when seedlings are produced from uneven-sized seed or when they are grown in crowded or nonuniform nursery beds. Just how much can be gained by a given percent of culling has not been established; neither has any general set of seedling specifications been drawn up. In Denmark[2] where labor costs are not high and good forest land is scarce, foresters find it profitable to cull up to 25 percent of nursery-grown Douglas fir seedlings before planting. Bushy and crooked seedlings, as well as small ones, are thrown out.

The percent to cull will have to be worked out for each species; furthermore, the percent will vary between different lots of seed for the same species. The percent of seedlings culled should be inversely proportional to the density of field planting. If the spacing interval is 4 x 4 feet and nine-tenths of the trees will be eliminated in natural or artificial thinning as the stand grows, then very little attention need be given to culling. But on the other hand, if a 12 x 12 spacing is used and every planted seedling is expected to develop into a crop tree, then nothing but high-grade, vigorous stock should be planted. Some safe general rules for coniferous seedlings for average-spaced plantations based on experience and practice are:

1. Discard seedlings in lower 10 percent by size; more if seedlings do not look thrifty or if they vary greatly in size.

2. For Douglas fir seedlings, roots should at least equal crown in length and weight for planting on a good site. Where site is average or poorer, particularly with regard to moisture, the roots should be proportionally larger.

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[2] Jørgensen, O. Marstrand, Denmark. Personal interview with author, April, 1946.

3. Discard seedlings that show abnormal tendency toward limbiness or crooked and forked stems.

4. Unhealthy-looking, diseased, or injured seedlings should be eliminated.

Seedlings should be graded sometime between lifting and field packing, depending on the method of operating in a particular nursery. Then, too, inferior seedlings should be discarded if encountered in the field planting operation.

Normally it is safe (and profitable) to figure on at least a 15 percent discard of seedlings between the nursery and the field plantation.

The Site and Its Treatment

Duff and litter on the forest floor are nature's fertilizer for the forest, and they also constitute the factory in which plant nutrients are made available through decomposition. If several inches of duff are present on the surface of Douglas fir soil, it means that decomposition is not taking place fast enough and insufficient soil nutrients are being made available for use. Little or no duff on the surface means that it has been destroyed by excessive burning or erosion and leaching. Both too much and too little duff are bad for Douglas fir growth; the former may be corrected and the latter avoided by careful handling. Where there is an excessive amount of duff and debris on the surface following a clear-cutting operation, a moderate or light burn, at the time when the lower duff and soil are moist, will remove excessive debris, reduce the immediate fire hazard, make more soil surface available for a seedbed, reduce competition, and convert surplus debris into plant nutrients for immediate use (all of this without serious injury to the soil). But here lies the difficulty: it is often all but impossible to get the desired light or moderate burn.

An excessively heavy burn, on the other hand, destroys all duff and shade, and destroys humus. This reduces moisture-holding capacity, and leaves the soil highly subject to drying out and to rapid leaching away of plant nutrients made soluble by burning. Such burning is almost certain to do more harm than good.

Incidentally, broadcast burning will kill all seed and seedlings present, most saplings, and some of the seed trees or reserve trees left after logging.

It is most desirable not to burn:

1. When there are seed, seedlings, or saplings already on the ground.
2. When debris and duff are not more than an inch or two deep.
3. When brush competition is not too heavy.
4. On severe sites such as poor soils or hot bottom lands.

Fig. 3—A 66-year-old Site III Natural Stand of

Douglas Fir near Cottage Grove, Oregon

Stands of this nature have an average height of 115 feet for dominant and co-dominant trees. The total number of trees 7 inches d.b.h. and larger is 270, average d.b.h. 12.5, basal area 229 sq. ft., volume 9,270 cubic feet, and mean annual increment 142 cubic feet. The largest trees are about 20 inches in diameter.

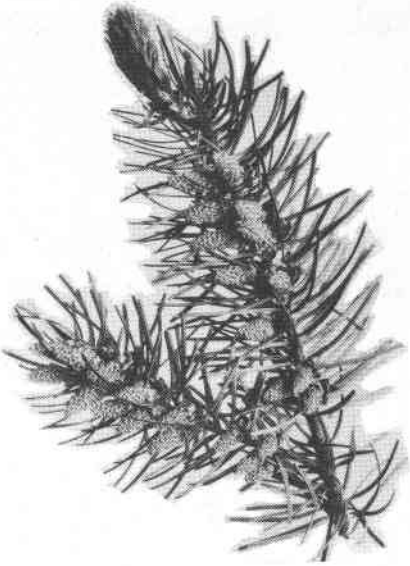

Fig. 4—Pistillate and Staminate Flowers of Douglas Fir

The large flower just below the terminal bud is the pistillate flower that later develops into the cone. The smaller flowers on the twig are the staminate flowers that produce the pollen.

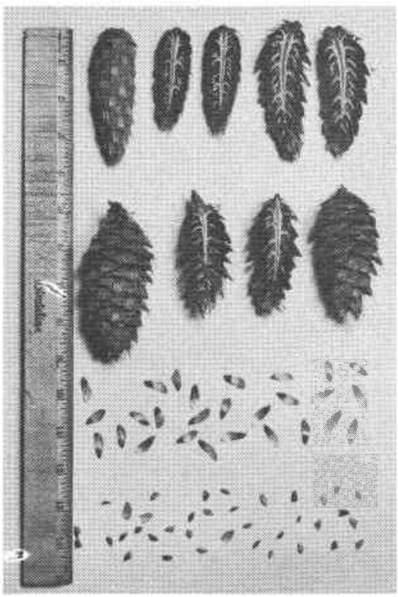

Fig. 5—Mature cones of Douglas fir showing cross-section and internal structure. Seeds with and without wings attached are shown at the bottom of the picture.

(Photo, courtesy West Coast Lumbermen's Association)

5. On south exposures.

6. When slash and duff are so extremely dry that a severe burn will result.

7. When soil is loose and burning is likely to result in landslides and erosion.

It is most desirable to burn:

1. When burning is essential for reasonable fire protection.

2. When slash or brush and other competition is so heavy that seedlings can not come in.

3. When it is desirable to favor intolerant species like noble fir and Douglas fir and to eliminate or retard tolerant species such as hemlock and silver fir.

Pure Stands of Douglas Fir and Soil Fertility

When heavy agricultural crops are produced, it usually follows that heavy fertilization is necessary if the high rate of production is to be maintained.

In this respect, the forest grower in the Douglas fir region may have a distinct advantage, for the soil appears to maintain its fertility under continuous production of heavy pure stands. There is seldom a heavy duff cover because decomposition of litter very nearly keeps pace with deposition, and through this rapid decomposition plant nutrients are gradually and continuously returned to the soil. Sample measurements of the first 25 years of ring growth on stumps of pure stands that were several hundred years old, usually show a very similar ring pattern or rate of growth to that of 25-year-old trees in the immediate vicinity. This is evidence that several hundred years of natural growth of pure Douglas fir has not depleted the soil or reduced its growth power for this species. However, in connection with a clear-cutting operation it is possible to reduce soil fertility through excessively heavy slash burning and erosion (30) and this frequently occurs.

Growth Rates and Yield on Different Sites

Fundamental facts of growth and yield of young-growth Douglas fir are contained in U.S.D.A. Tech. Bul. No. 201 (42), therefore related factors only will be covered in this publication.

Tables and figures in the yield bulletin are based on normal fully stocked stands. Adjustments must be made when applying these tables to stands with an abnormal distribution of size classes. The yields are based on what was found in the different-aged stands at the time of measurement. If any form of successive thinning or stand improvement is contemplated (Fig. 2), which will salvage trees that would otherwise fall out of the stand, or which will bring about an increased growth of crop trees, the applicable table will have to be revised upward. A full discussion of improvement cutting is given in *Management of Second-Growth Forests in the Douglas Fir Region* (18).

Quality is mentioned but in no way enters into the calculations of volumes. But quality is a particularly important feature of yield in understocked stands that approach normality as they grow older. Such stands approach normal stocking not because there is an increase in the number of trees but because there is little or no loss, so that as the stand grows older fewer trees per acre are required for full stocking (14). Also ultimate crop trees that had wider spacing in their earlier years make better diameter growth. Stands that develop in this fashion have larger limbs and shed them less readily; therefore they produce more volume but a very much poorer quality of lumber at rotation age than stands which develop with heavier early stocking. Development of heavily stocked young stands is accompanied by self-pruning and loss in number of stems by suppression. This is of vital importance in management plans for tree farms and private forestry projects where a high quality of product is contemplated.

On long rotations, growth rates on the better sites in this region are superior to growth in most other forest regions of the Nation. But scattered throughout the region there are limited areas of poorer sites (sites IV and V). These poorer sites become the problem areas under intensive or industrial management, but they often present features other than growth rate that make them approach in value the better sites. Their usual advantages over better sites are these:

1. They restock more readily than better sites and this often may partially or entirely avert the cost of planting.

2. Normally they have more than the required stems per acre, and when there are markets, Christmas trees, poles, and thinnings can be sold to retire all early costs of establishment and maintenance.

3. Dense stands prune earlier and produce more clear, close-grained, high-value material (49).

4. Prompt and adequate restocking coupled with less rank growth of other vegetation often reduces the fire hazard.

Poor sites often occur immediately adjacent to, or in a patchwise mixture with, better sites; neither site can be handled separately. For that reason good and poor sites must be carried as a whole, just as low-paying but necessary factors are carried in any big business.

Relation of Growth Rate to Wood Quality

It is frequently stated that with the development of wood substitutes and plastic products the need for high-grade lumber will disappear, but experience has provided a contradiction. With the disappearance of high-quality virgin growth and the increase in supply of low-quality young growth the spread between the price of high and low grades of lumber is constantly increasing. For that reason the production of high-grade material will be most profitable when Douglas fir is grown under management.

Wood quality (43), whether strength or other, is not directly proportional to rate of growth but, generally speaking, extremely fast or extremely slow growth is associated with poor quality. More important than annual ring width is a generous proportion of summerwood in each individual ring and uniformity of ring width throughout the life of the tree (48). Size, frequency, and condition of knots (49) are also important quality factors.

Not less than one-third summerwood and not less than six annual rings to the inch are the minimum standards for good strength quite generally accepted for Douglas fir lumber. To this requirement should be added one for small, tight knots. These standards establish the objectives for growing Douglas fir under management. They are not inconsistent with, nor do they work in opposition to, the development of fast-growing, superior strains of trees. In fact, they permit the growing of two-foot trees in a 75-year period; and since the ring width and size of limb (or knots) can be controlled by maintaining the proper stand density, the production of high yields per acre and high quality can go hand in hand.

Stand Density, Thinning, and Pruning

A forest sufficiently dense to fully utilize the productivity of the soil and prevent excessive lower-limb development during the first 25 years of life is the first requirement for a stand that will produce both high yield and high quality. This means an average of 600 trees per acre in planted stands and more in natural stands, which will have poor distribution. Poorer sites require a slightly greater density and better sites slightly less.

Usually from about the twenty-fifth year in the life of the stand, suppressed trees (or trees of some other crown class) will have to be removed by successive thinnings. This maintains a uniform width of growth ring and utilizes the trees that naturally fall out as the stand develops. On the better sites in accessible locations, some thinning can be done profitably with 1947 markets, and this will probably become increasingly profitable as time passes (50). But thinning probably never will be profitable in the rougher topography and most remote areas. In such localities a slightly lower than specified density, but sufficient to insure good quality of final timber crop, will be acceptable.

Pruning may also be done by about the twenty-fifth year when the ultimate crop trees assert their dominance in most Douglas fir stands. At that time crop trees can usually be identified, and they can be pruned at a low cost from the ground by using hand and pole saws. Then too, at 25 years the limbs in an average stand are dead or beginning to dry up to an average height of 19 feet. As a result, the 18-foot butt log can be pruned without reduction of growth, entrance of decay, or other harm to the tree; this has been proved by studies at the Wind River Experimental Forest.

Despite high wage costs, pruning at age 25 may be profitable. It has been estimated that an average 75-year-old natural stand will produce less than five percent of lumber in select grades. If the last 50 years of growth in every 18-foot butt log were clear, however, the percent of select grades might run from 25 to 30 percent of the volume. The Wind River studies indicate that it requires .5 man-hours to prune enough trees at 25 years of age to produce a thousand board feet at 75 years of age. It is not difficult to see that the difference in lumber-grade recovery would pay a high return on an investment in pruning. Other ages of pruning and other heights of pruning might be equally profitable, but figures for proof are not available.

Geographical Races of Forest Trees

Besides the foregoing general knowledge of how Douglas fir grows, specific knowledge of variations in growth and development of the species will help make possible an improvement in the ultimate crop when new forests are grown. In rather recent years geneticists have shown that the formation of geographical races of species, adapted to the climate and other environmental conditions of their given locality, involves hereditary changes in the trees of a stand (17). Thus, forest trees growing in given localities have hereditary differences in their growth, their resistance to disease and insect attack, or their climatic requirements. Such differences constitute an opportunity for improving the Douglas fir forests of the future.

Schreiner (59), Chief of the Division of Genetics in the Northeastern Forest Experiment Station of the U. S. Forest Service, states: "The existence of physiological or geographical races of forest trees is no longer a matter for debate nor is it necessary to design research to prove that such races exist. The fact that they do exist is now generally accepted. Investigations over the past sixty years have shown that in many, if not all, important forest species there are rather distinct races or strains that differ in their hereditary response to a given complex of environmental conditions. The problem now is to determine which geographic race is best adapted to each particular region where planting of a species is to be undertaken."

Munch (15) in his textbook points out that the individual tree does not develop hereditary characteristics but that races develop through variation in offspring. He recognizes certain factors in race formation. "The following factors of a locality have, up to the present, become recognized as environmental influences which lead to the formation of morphological local races: Snow, wind, heat, and length of growing season, summer warmth, frosts—early and late, soil races, disease and pest resistance."

The relation of races and strains to height growth is particularly mentioned by Munch (15), and he quotes other authorities. "Height growth differs according to climatic race. Trees from an unfavorable climate, especially from elevated or northerly situations, even when transplanted to a favorable climate grow more slowly from the first than trees of the same species from a better climate, as has been proved by comprehensive researches by Cieslar, Engler, Schotte, Munch, and Burger."

The individual tree does not gradually adjust itself to surrounding conditions and become acclimated, and thus develop a local race or strain of tree species. But, if the tree survives and reproduces, its offspring will have considerable inherent variation. The offspring most suited to survive in the environment will no doubt constitute the next generation *whether or not* it happens to be superior in growth rate, form, or quality. The individuals best suited to survive in the second generation will again survive, and so on, until a distinct race or strain has developed. Thus, there is in nature ample opportunity for the development of races or strains of trees with poor, medium, or good growth and form. Local races or strains may have fixed growth rates. They also may be quite specific in their climatic requirements. A good growing strain when placed on a suitable site is easily recognized by its performance, but a strain with a low growth rate may be difficult to distinguish from a good-growing strain placed in an environment to which it is not adapted.

The failure to recognize the existence of superior (or inferior) races or strains of forest trees, and failure to recognize limitations in adaptability to a foreign, or even slightly different, site has been one of the chief causes of failure or loss in the history of artificial reforestation throughout the world. That is a sweeping statement, but true nevertheless; and many countries, including America, are paying dearly for their carelessness in this respect.

There have been a few lucky instances in the introduction of tree species that have been unusually successful. Douglas fir and Sitka spruce (*Picea sitchensis*) are being grown very successfully over a large area in Europe, but this did not occur unless, by chance or careful selection, European growers obtained strains of these species suited to their sites. The most outstanding introduction was that of Monterey pine (*Pinus radiata*) in New Zealand, Australia, Chile, and South Africa. Associated with these successful introductions were many dismal and costly failures.

Some records of races of Douglas fir are available and will be given, but more complete records of provenance[3] studies of some other well-known conifers will help to illustrate and emphasize the significance of geographical races.

Strains of Scots Pine (Pinus sylvestris) *in Europe*

Romell says this of Scots pine in Sweden (54): "Towards the middle of the century (19th) a remarkable importation was brought in from Germany. This seed of unverified origin came mostly from Darmstadt, but may very probably have come from Hungary and was not long in causing great or fatal damage. The cultivations so splendid at the beginning, those

[3] "Provenance" is a term used to indicate the place of origin of seed and may represent a race or strain. It is given somewhat different spelling and pronunciation by different European nations, but "provenance" is the commonly used English term.

coming from the south showing ordinarily in youth more rapid growth than those from the north, soon began to degenerate. Usually this degeneration took on the aspect of a 30-year catastrophe and most of the stands never attained the age of 40 years. The wood produced was of a lower quality (than trees from the north) and the form of the bole was very bad so that the wood could only be used for firewood."

This failure was apparently due partly to poor strain of seed and partly to climatic unsuitability. Baldwin (9), who made some study of it, states: "Thus the observation that Scots pine grown in Sweden from German (Darmstadt) seed forms a large percentage of crooked stems, together with research confirming this fact, has resulted in certain prohibitions on the importations of seed from countries to the south."

Scots pine gave similar results practically every place it was tried. Lubyako at Moscow (41) reports as follows on use of local strains:

"Eleven-year-old progenies of first-quality stands (of Scots pine) averaged 1.8 times in height and over twice in diameter as compared with those of third-quality stands."

Engler (21) in Switzerland tells of good and poor strains of Scots pine growing side by side:

> The pine produced from German seed in Livonia and Sweden are not only of poor form, but they are early subject to disease and die in large quantities at the age of twenty to thirty years.
>
> My researches showed that the progeny (of Scots pine) is of poor form when the poor form of mother trees is caused by poor soil conditions.
>
> The old spontaneous pines of the Zurich state forests of Rheinau are faultless in growth in spite of the relatively poor and dry soil, and the thirty to fifty year old trees of exotic seed are not comparable as regard to stem form; and that this difference should disappear (as trees grow older) is unthinkable.

Similar variations in Scots pine were found in American plantations and the results are well known to American foresters.

Strains of Loblolly Pine (Pinus taeda, Linn.) *and Ponderosa Pine* (Pinus ponderosa, Law.) *in the United States*

Some tests of well-known American species show definitely the existence of strains with superior growth qualities for a given site. In Louisiana (63) a local strain of loblolly pine seed produced 20 percent better height growth and approximately double the cubic-foot volume in the first 15 years than was produced by seed from Texas (350 mi. west), Georgia (450 mi. east), and Arkansas (350 mi. north). All strains were well within the range of the species, and Georgia and Texas strains were at a similar latitude and elevation. The local strain was also less subject to disease.

A test of ponderosa pine was made by Weidman (64) at the Priest River Experimental Forest in northern Idaho. Seeds from twenty widely selected sources in western United States and Canada were tested side by side in plantations beginning in 1911. Local strains made good growth, but two introduced strains made better—strains from the Lolo and Bitterroot National Forests were superior to local strains in both growth and hardiness. The best strains tested made more than twice the height and diameter growth of the poorest.

These examples show the regularity and extent to which variations in strain occur in well-known trees. Douglas fir has similar if not greater variations in geographical races.

Strains of Douglas Fir in Europe

Plantings of Douglas fir in Europe have shown both poor and good growth from the different geographical races. The most complete report, based on a summary of existing experiments and most of the important reports to date, was that by Hans Kanzow (33) in 1937. Some of his comments are as follows:

> The growth of Douglas firs from various origins (19 localities in western United States) differs widely. At the age of 25 years, trees of the most thriving origin are on the average three times higher than those of the poorest growth. The differences of various degrees found in the parallel experiments are the result of racial characteristics.
>
> In contrast to the excellent growth of the Douglas fir first planted in Germany, we find that the trees of only two of the 19 origins of the Schwappach experiment show unusual rapid growth. The trees of most rapid growth are those of origin No. 15 and in somewhat less measure No. 16, Snoqualmie. [The general vicinity of Darrington, Washington.]
>
> Great and unexpected differences in growth and power of resistance to frost between the various Douglas fir races forces us to pay particular attention to the origin of the seed—despite the great number of questions which we have not yet answered, particularly in regard to races of Douglas fir and their suitability for Germany.
>
> We warn against the purchase of seed coming from crippled stands from which it is easily collected and which grows in the rain-protected section of Washington, until it has been proven that the crippled growth is only a result of the influence of the environs.

Boyce (13) following a trip through Europe states: "The races of *Pseudotsuga taxifolia* are of great importance to foresters in Germany and in fact all Europe because of the extremely different rate of growth and reaction to disease and insects." (See statement under Susceptibility to Disease on page 54 of Boyce's report.)

Strains of Douglas Fir in America

Detailed records of tests of strains made in Washington and Oregon will be given after the discussion of climatic requirements on page 27.

Variation in growth and form has received most attention and is so well known abroad that European foresters make special provisions to secure seed from specified locations even to the extent of sending men here from Europe to make collections. C. Syrach Larsen and O. M. Joergensen were in the region in 1946 in the interests of the Danish Government to trace accurately the source of Douglas fir seed now being used and to locate strains of good growth and form that were also climatically suited to their country. Suitable areas were sought out for seed collection, and cuttings were made of selected trees. The cuttings were sent to Denmark by air mail for grafting on local stock, and published records (39) of their success are already available. During 1938 (6) an American officer was paid by Germany to certify the source of Douglas fir seed imported from northwestern United States. A forester was here during 1945 from The Netherlands (A. B. Kruik) seeking suitable Douglas fir for rehabilitation of The Netherlands' forests, and during 1946 a forester from Italy (Aldo Pavari) was here for a similar purpose. A forester from Iceland (Vigfus Jakobsson) at the University of Washington from 1943 to 1946 spent his summers seeking suitable strains chiefly of spruce for Iceland.

Although American foresters are beginning to recognize these varied strains, until recently little or nothing was done to secure the best strains of seed for American Douglas fir reforestation projects.

Variations in Cones and Foliage of Douglas Fir. Besides variations in growth rate and hardiness, variations in cone and foliage have been noted in Douglas fir. The bracts on the cones of the mountain forms are notably longer than on the coast variety, and in many instances the bracts turn down over the cone scales. Also, as previously mentioned on page 8, the mountain forms have blue and gray colors and the coast forms green foliage, with wide variations in each group.

Many isolated specimens of "weeping" foliage are on record. Dallimore and Jackson (16) list a dozen varieties based on foliage variation. Hanzlik (27) has reported a considerable stand with distinctly upward curling foliage growing wild in the vicinity of Bee Hive Mountain in the Wenatchee National Forest (Washington).

Variations in Resistance to Insect Infestation and Disease. Douglas fir (and other species) may be notably subject to insect infestation and disease when moved to a new environment. Sometimes susceptibility is so pronounced as to become a limiting factor for an otherwise suitable species or strain. Usually the infections or infestations are present in the native habitat but do not develop to dangerous proportions until the tree has been moved to a new environment where conditions for development of diseases or infestations are more favorable.

Dr. J. S. Boyce (13) in 1939 visited many of the important European plantations where United States strains of Douglas fir were used; some of his comments are as follows:

> At Eberswalde, Germany, there are sample plots of 28-year-old *Pseudotsuga taxifolia* from nineteen provenances in western United States. Snoqualmie (Washington) provenance was best of all by far with Pecos (New Mexico) provenance best of the mountain forms. Among the provenances of the mountain forms there were differences in susceptibility to *Rhabdocline* (needle blight) between provenances and also between individuals within a provenance. The coast (Oregon and Washington) forms were not infected.
>
> At Buunderkramp (near Wageningen, Holland) there was a 30-year-old stand with three forms (of Douglas fir) mixed. *Rhabdocline pseudotsugae* (needle blight) was severe on mountain forms; coast forms were not infected. *Chermes coolyi* (bark lice) was severe on the coast form, occasional on intermountain form, but the mountain form was not infested. Where seen, at several places in Holland and at Eberswalde, Germany, *Rhomopsis peudotsugae* (canker of Douglas fir) was confined to the coast form.

Richens (52) reports similar susceptibility of strains. "Racial differences in resistance to *Phaeocryplopus gauemanni* (*Rhode*) *Pet.* and *Rhabdocline pseudotsugae Syd.* have been found by Buchwald (1939) and Gerlings (1939) respectively. Susceptibility to bracket fungi appears to be an hereditary characteristic according to Olen (1942[a])."

Although insect infestations and disease are not a serious problem in existing young-growth stands in the Douglas fir region, they could easily become a problem when local races, or strains, are shifted to a strange or new environment. Munger and Morris (47) report: "In the spring of 1938 a needle blight was noticed on a very large proportion of the trees on the Siuslaw plantation. This has been tentatively identified as *Rhabdocline pseudotsugae;* the results would indicate that the progeny from certain localities may be more susceptible to the disease (than others) although the differences are not great. The results would indicate also that there is a significant difference in susceptibility of the progeny of certain parent trees within the same locality of seed source."

A strain of Rocky Mountain Douglas fir growing in the Wind River Arboretum at Carson, Washington, is so heavily affected with needle blights (*Rhabdocline* and *Adelopus*) that some trees have lost nearly all their foliage and are dying.

Climatic Requirements and Limitations of Forest Trees

Authorities differ as to what constitutes the most vital climatic factors in tree growth, but most agree that the factor which may be important or limiting for one locality or species may be unimportant for other localities or species. Baldwin and Shirley (11) state: "The mean temperature of the growing season seems to be the best single factor since it takes account of altitude. Length of growing season and early and late frosts follow. Minimum winter temperature is also important."

On the other hand Baldwin (8) quoting Wiebeck (1929) has offered evidence that mean annual temperature provided a better criterion for zoning local races than do summer temperatures.

Rudolf's (55) introductory statement in his summary of "Source of Seed" section in the seed manual of the U. S. Forest Service is as follows: "Forest trees and shrubs have developed climatic races or strains within species. Each race is peculiarly adapted to thrive under the conditions in which it developed. Unless seed of proper origin is used in forest planting, serious failures may result despite the fact that the right species was used on the planting site." Proof of his statement lies in the records of forest plantations throughout the land.

Normally Douglas firs and most forest trees in temperate climates start growth before the last frost in the spring and stop growth before the first frost in the fall. In other words, the growing season does not coincide with the frost-free period. Yet frost-free period usually constitutes the best measure of the length of the growing season in the temperate zone; in two areas similar as to soil and rainfall, the annual growth rate is usually proportional to the length of the frost-free period. Adaptation to length of growing season often becomes so fixed as to be classed as an hereditary characteristic, so that trees moved from a warm climate to a cold climate may suffer from early and late frosts.

Ordinarily it is not one factor alone that determines climatic suitability of a species or strain but rather a combination of factors. A tree may be capable of surviving low winter minimums but may be killed off by late spring frosts, while a different strain of the same species that has developed under a short growing season may survive the late spring frosts and be killed off by low winter temperatures. Both maximum and minimum temperatures are of great importance in connection with seedling establishment and early growth. Average annual temperature, average summer temperatures, and length of frost-free period are of vital importance in the ultimate growth and development of the stand. The frost-free period is associated with minimum temperatures since a short frost-free period would indicate late spring frosts that might result in seedling mortality and the killing back of the new growth on twigs.

Both the amount and time of precipitation are important to seedling establishment and ultimate growth. There must first be sufficient moisture for seedling germination and establishment and then sufficient rainfall during the summer to permit growth while temperatures are favorable. In areas of high annual rainfall, trees may show a low growth rate if the rainfall does not occur during the growing season. On the other hand, Douglas fir or other species may survive and make a reasonable growth in areas of comparatively low rainfall if the rainfall occurs during the growing season. Just what constitutes growing temperatures has not been established for different species, but a temperature of plus 6°C (43°F) has been set up by Langlet (38) as the point where significant tree growth starts.

Records of American and European experiments were studied carefully by the author for specific examples of tests of the climatic limitations of Douglas fir; but few were found, and none was directly applicable to this region. In his studies of the relationship of forest types to climate in the Southwest, Pearson (51) made some tests of the climatic requirements for the strain of Douglas fir that is native to that locality. Minimum requirements for Douglas fir in northern Arizona were set up as June to September mean air temperature 55°F, mean maximum, 62°F, annual precipitation 26 inches, May to September precipitation 12 inches. Optimum condition of both temperature and precipitation are higher than those shown, but often in that locality as one factor goes up the other goes down with a change in elevation. Thus, as elevation increases, temperature becomes the limiting factor, and as elevation lowers precipitation becomes the limiting factor. Since the Southwest is so different climatically from the Douglas fir region of western Washington and Oregon it is not probable that these climatic limitations would be applicable to this region.

Eneroth (20) has shown quite conclusively that seeds sown on sites 1°C colder (mean summer temperature) than point of origin give about one-third poorer results than at point of origin. He holds that cone lots should be kept separate for each 100 meters (328 feet) altitude (in Central Europe). As nearly as could be determined this work applied chiefly to Scots pine.

Climatic limitations of Sitka spruce were shown by Hagem (26). Seed from along the Washington coast that was planted near Bergen, Norway, in 1917 showed 100 percent loss of seedlings from frost by the end of the second winter, while seed collected near Juneau, Alaska, showed a loss of thirteen percent. Again in 1922 seed from the Washington coast showed a loss of 100 percent of seedlings the first year (winter) while that from Kruzow, Alaska, showed only a 10 percent loss.

Climatic Requirements of Douglas Fir in the Pacific Northwest

Douglas fir will survive under an extremely wide range of climatic conditions, but records and experience indicate that any one particular strain of this tree will produce a profitable timber crop only under a rather limited climatic range. To survive is one thing. To make a maximum or profitable sustained growth may be something entirely different. It is this ability to survive under a wide range of conditions that has confused many foresters who have planted Douglas fir but have not watched it long enough under management to see it develop to timber or harvest size.

There are numerous examples of climatic unsuitability in early Forest Service plantations of Douglas fir. Five plantations were established in the Mt. Hood National Forest (Still Creek) in 1915. Seed was obtained from elevations under 1,000 feet, and the elevation of plantations varied from 3,300 to 4,500 (Figs. 7A and 7B). Early survival was good, but the 1938 examination showed tops frozen and trees dead above the snow line on all except lower slopes and protected canyons. Immediately adjacent plantations were established in 1918 from seed collected at elevations from 3,800 to 4,500 feet. The 1938 examination showed that these plantations were in good shape and were not being injured by frost.

A plantation is reported (36) in the Siuslaw National Forest in which seedlings from the same low-altitude seed source were planted at elevations from 800 feet to 3,100 feet. The lower end of the 30-year plantation at 800-foot elevation (Figs. 8A and 8 C) is now near piling size while the upper end at elevations above 2,500 feet consists of scattered stunted trees (Figs. 8A and 8B). Slower growth is to be expected at the higher elevation; but existing snags show that a good forest once grew there, and scattered volunteer trees from local seed show that good stands could grow there now if the right planting stock was used. The plantings from Benton and Santiam seed sources reported on page 31 are other examples of stocks not climatically suited to sites where planted.

Variations in Drought Resistance and Root Development

Finally, variations of Douglas fir strains as to drought resistance and root development have been reported. Dr. Donald B. Lawrence[4] (in private studies) planted in fine river sand in his garden at Bridal Veil, Oregon, Douglas fir seeds from the east or dry end of Columbia Gorge (annual rainfall 20 inches) and seeds from Bridal Veil at the west or wet end of the Gorge (annual rainfall 60 inches). During midsummer drought period he allowed the beds to dry out, and found that most of the progeny from the wet location died while most of those from the dry site survived. Upon examination he found that seedlings from the dry site had a smaller crown and a deeper and better developed root system than those from the moist site. This may be an important consideration on hot, dry south and west exposures even in the moist timber zone if there is ample moisture during the year as a whole but insufficient during the growing season.

It has also been observed that root form differs for different climatic races of other species. Spruce from high mountain races are more strongly rooted than progeny of lowland races (15).

A STUDY OF GEOGRAPHICAL RACES OF DOUGLAS FIR IN THE PACIFIC NORTHWEST

The most authentic, and probably the only positive evidence of the performance of Douglas fir races in western Washington and Oregon is contained in the records of U. S. Forest Service plantations. These include studies of survival and growth of Douglas fir from known seed sources that have been under way since 1911 and have been reported on by Munger and Morris (46). In addition to data on geographical races, the work provides information on climatic limitations, effect of soil and site, susceptibility to disease, age of parent tree, variation within strains, and many other phases of the seed-source problem; it is the foundation for discussions in this report.

Seed from thirteen widely scattered localities in western Washington and Oregon representing a total of 134 different parent trees of various ages and descriptions was tested. The progeny were first tested for growth and vigor side by side in the Wind River Nursery at Carson, Washington. After 3 years in the nursery, they were planted in the field on five widely scattered locations that vary in elevation from 1,000 to 4,600 feet. The mildest site, although not the lowest in elevation, was a humid slope of the Siuslaw National Forest at an elevation of 2,100 feet, along the Oregon coast. The most rigorous site was a 4,600-foot elevation in the high Cas-

[4] Lawrence, D. B. Unpublished results of private studies at Bridal Veil, Oregon. 1942.

cades near Mt. Hood. The plantations were checked for survival and growth at five-year intervals since the date of establishment. The last examination, made in 1941, was covered by a mimeographed report by Munger and Morris in 1942. Table 3 taken from this report compares the height of

Table 3—*Rank* by Height in 1931, and Average Diameter and Rank by Diameter in 1941, of Trees Grown in Three Plantations Established in 1915 from Seed Collected in Thirteen Different Localities*

Seed Source Locality†	Elev.	PLANTATIONS: Wind River Site III Elev. 1300			Siuslaw Site II Elev. 2100			Mt. Hood Site IV Elev. 2800		
		1931	1941		1931	1941		1931	1941	
		Rank	Diam., *In.*	Rank	Rank	Diam., *In.*	Rank	Rank	Diam., *In.*	Rank
Palmer	2500	2	5.8	2	4	6.6	2- 3	1	3.2	1- 2
Gates	950	6- 7	5.7	3	9	6.3	5	4	3.1	3
Granite Falls	400	1	6.0	1	3	6.2	6	3	2.7	4- 5
Darrington	500	3- 5	5.2	6- 7	1	6.5	4	6- 7	2.7	4- 5
Carson	400	13	4.9	12	5- 6	6.0	7- 8	10-11	2.2	10-12
Wind River	1300	10-11	4.8	13	8	5.1	12	10-11	2.2	10-12
Lakeview	100	8- 9	5.1	8-10	5- 6	6.0	7- 8	8	2.4	9
Portland	300	8- 9	5.1	8-10	10	6.9	1	12	2.1	13
Fortson	500	3- 5	5.3	5	11	5.7	9	6- 7	2.6	6- 7
Benton	700	6- 7	5.5	4	2	6.6	2- 3	13	2.2	10-12
Hazel	900	3- 5	5.0	11	12-13	5.2	11	5	2.6	6- 7
Racetrack	2600	12	5.2	6- 7	7	5.5	10	9	2.5	8
Santiam	3500	10-11	5.1	8-10	12-13	4.8	13	2	3.2	1- 2
Average (Weighted)	......	......	5.3	......	......	5.9	......	......	2.7	......

* The rank of each seed-source locality is in numerical order according to the average size of the progeny therefrom, number 1 being the largest, regardless of the significance of small differences. Localities having progeny of the same average size are given the same rank numbers. If, for example, three localities have the same average each might bear the rank 1-3.

† Location of areas: Darrington, Washington; Fortson, Washington; Hazel, Washington; Granite Falls, Washington; Lakeview, Washington; Racetrack, Columbia National Forest, Washington; Wind River Experimental Forest, Washington; Carson, Washington; Palmer, Oregon; Portland, Oregon; Gates, Oregon; Santiam River, Oregon; Benton, Oregon.

progeny from different seed sources in 1931 and their diameters in 1941 for the three most representative plantations. It will be noted that some stocks were superior in height growth in 1931 but not superior in diameter growth in 1941. They may still be superior in height growth, but height measurements were not taken in 1941. The plantation at the 4,600-foot elevation was not included in this table because of abnormal losses due to frost and stormbreak, and a plantation of the Snoqualmie National Forest was eliminated because it had been partially destroyed by rodents.

Site determinations were not made of seed-source areas, and no effort was made to sample all sites when seed was collected. However, recent general site classification for Douglas fir would probably rate areas as follows: Site IV would include Santiam, Racetrack, and Lakeview. Carson, Wind River, and Portland would follow in Site III. Granite Falls, Darrington, Fortson, Hazel, Palmer, Gates, and Benton would fall within the limits of Site II. Unfortunately Site I was not represented at all in either the seed-source areas or the plantations where the seedlings were outplanted. The plantation sites are: Siuslaw II, Wind River III, and Mt. Hood IV as shown in the table.

Since Douglas fir site classification is based on height growth alone, growth indicating a good site may be the result of either a superior-growing race or superior growing conditions (or both); it is sometimes difficult to differentiate between the two. Neither the general literature on the subject nor this study of Douglas fir progeny provides conclusive means of deciding whether an instance of superior growth is caused by inherent growth qualities of the seed or by favorable soil and climatic conditions. The study presents convincing examples of both and still other examples in which it is impossible to decide between the two.

Stock from seed collected in the vicinity of Granite Falls, Washington, and Darrington, Washington, at an elevation of around 500 feet made either the best or better than average growth on all planting sites regardless of climate, even up to an elevation of 4,600 feet. Another stock that made more consistently good growth than these two stocks was that obtained from seed collected at Palmer, Oregon, at an elevation of 2,000 to 3,000 feet; stock from seed collected in the Willamette Valley at Gates, Oregon, at an elevation of 950 feet made nearly as consistently good growth. The fact that the Palmer stock made superior growth wherever tried, even where the competing stock was grown from seed collected in the immediate vicinity of the plantation, is positive evidence that it comes from a superior-growing strain of Douglas fir with a wide climatic tolerance. The wide range of elevation between seed sources and planting sites is fair proof

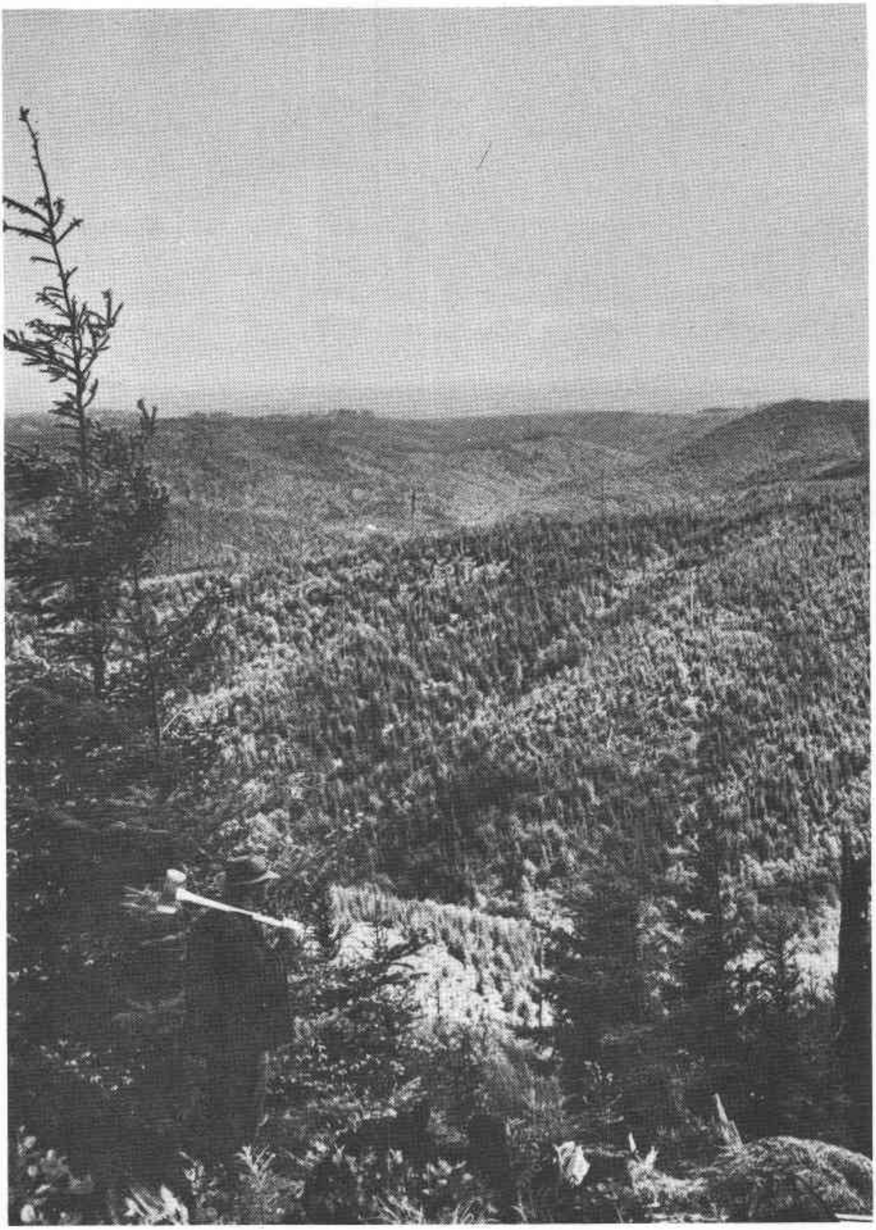

Fig. 6—Looking Back. Natural regeneration followed the retreating edge of virgin timber as this area was clear-cut and broadcast-burned. The area is well stocked but not fully stocked. It is now part of the Capitol Forest of the State of Washington.

(Photo, courtesy West Coast Lumbermen's Association)

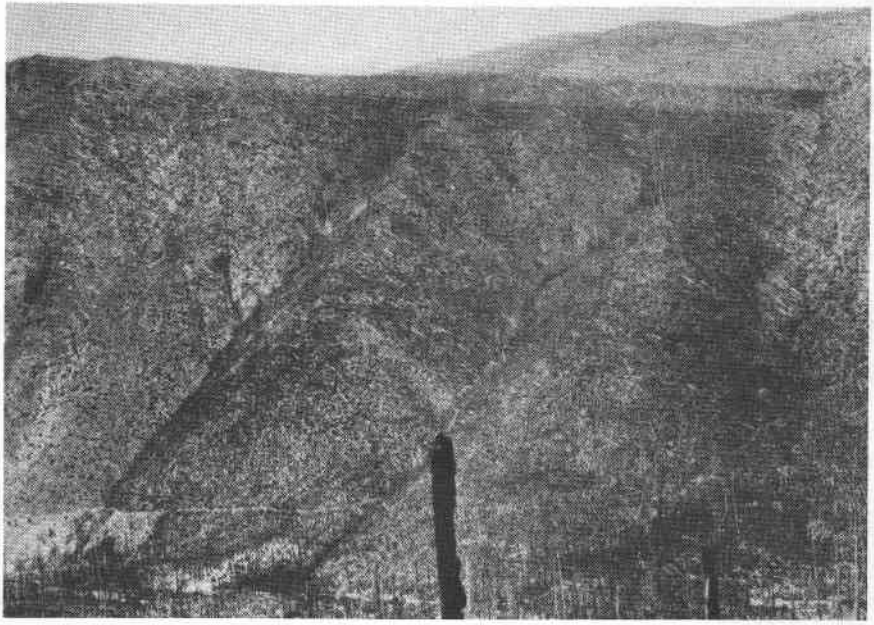

Fig. 7A—A planting site where the elevation varied on a single slope from 2,600 to 4,600 feet. Trees grown from seed collected at elevations below 1,000 feet are surviving and making good growth only on protected slopes and at lower elevations. Adjacent plantations grown from seed collected at a 3,800-foot elevation are uninjured by frost and making good growth to the top of the ridge. (See next photo, Fig. 7B.)

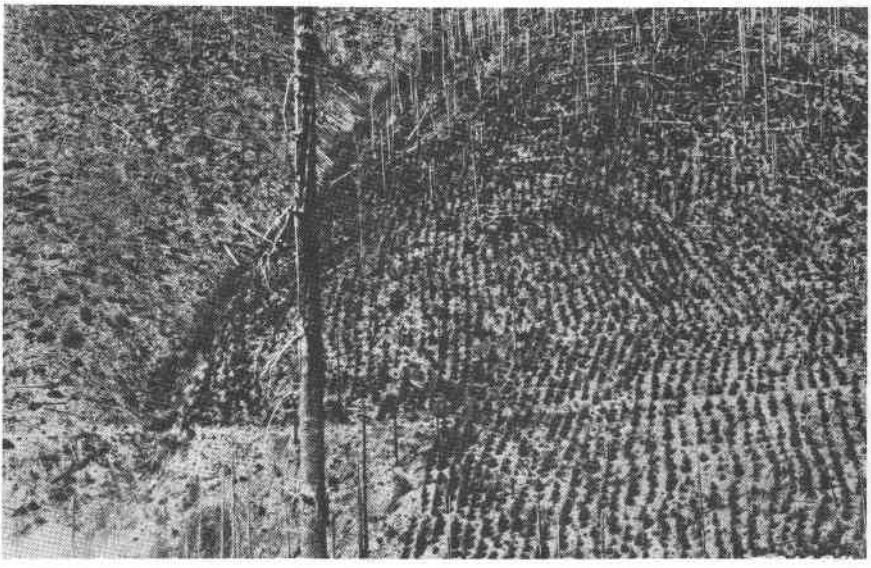

Fig. 7B—A close-up of lower left corner of previous picture showing good survival on plantation at the lower elevation. The area along the left side of the picture was not planted.

that this superior growth is not the result of favorable climate at the plantation site alone.

Stock from seed collected at Fortson and Hazel was nearly equal to Darrington stock on the inland Wind River and Mt. Hood plantations but was decidedly below it on the humid coast Siuslaw plantation. Since each sample of seed came from several good parent trees, and seed sources lie within a few miles of each other, a difference in strain is the only explanation of this variation in growth rate. All these areas lie in the same valley bottom; Fortson has the same elevation as Darrington, and Hazel is only 400 feet higher. This is not only evidence of variations in strains but evidence that they can originate within a short distance of each other.

On the other hand, the growth of trees from seed collected on a humid coast site at Benton, Oregon, is good evidence of a strain not suited to a different climate. In both diameter and height the Benton stock made next to the best growth of all lots tested when planted on a similar coast site on the Siuslaw plantation. It made about average growth on the Wind River plantation where the climate is somewhat colder and less humid, but on Mt. Hood plantation that is still less humid, colder, and higher, it made the poorest growth of all thirteen strains tested.

Again, the mountain stock from Santiam, Oregon, made next to the best showing on the high plantations on Mt. Hood but made the poorest showing on the humid coast Siuslaw plantation. Racetrack, still another mountain stock, was average or below on all plantations.

It has been previously stated that the progeny best suited to survive on a site will ultimately prevail with the passing of tree generations, whether it happens to have a superior growth rate and quality or not. The progeny from two lots of seed in this study indicate that the strains have become poorer in growth instead of better in their own particular localities.

One lot of seed was collected near the Wind River Experimental Forest at an elevation of 1,300 feet, and another lot was collected seven air line miles away near Carson, Washington, at an elevation of 400 feet. Progeny of the Wind River seed made next to the poorest growth of any of the thirteen lots tested on the Wind River plantation. Trees from seed collected at Carson, Washington, seven miles away and at a slightly lower elevation made almost equally poor growth. On the Siuslaw plantation, a warmer and more humid site along the Oregon coast, stock from these two sources made a somewhat better showing, but was still below average. Progeny from these lots of seed made poorer growth in the plantation in the immediate vicinity of the seed source than was made by progeny of seeds brought in from eleven widely scattered sources (some from poorer sites). This is convincing evidence that seed used in this test from the Wind River locality was inherently inferior and below average in rate of growth and development.

The cause of the poor growth rate from the Carson and Wind River seed in all plantations was not determined, but poor growth rate is quite generally considered capable of becoming an inherent characteristic whether it develops from poor soil, lack of moisture, a short growing season, or some other cause.

One seed source tested, Lakeview, Washington, presents somewhat of a contradiction. The parent trees were making very poor growth. The soil was poor (sand and gravel) and the moisture content and water table dropped rapidly at the approach of summer, but the area had a frost-free period longer than some of the best growing sites. Another important point is that the trees from which seed was collected were (so far as can be determined) first generation trees on this gravel plain, and there are better growing sites within a few miles. Instead of making poor growth as was expected, the stock from seed collected on this area made average or only slightly less than average growth on all areas tested. Either the strain has not been growing on the poor site for sufficient generations to have the slow growth become a fixed hereditary characteristic, or the fact that the locality had a long growing season made it possible for this stock to make average growth when planted on better sites.

Evidence from these plantations of superior growth by strains from the vicinity of Darrington, Washington, is supported by the record of a large scale (1936) Forest Service plantation in the Willamette National Forest near Oakridge, Oregon. Stock from seed from a 3,000-foot elevation in the Snoqualmie National Forest near Darrington was planted side by side with stock from seed collected at a similar elevation on the Cispus and Toutle Rivers in the Columbia National Forest. Planting stock was similar in size and appearance, but by the end of the third year there was a loss of two-thirds of the Cispus-Toutle stock. Only one-third of the Snoqualmie stock was lost, and the Snoqualmie planting was larger and looked more thrifty. Here the strain showed not only a better growth but a better survival than the other seed sources.

An older (1915) plantation near by (Dead Mountain) showed a similar variation. Stock from Stillaguamish River (in northern Washington) seed was planted side by side with stock from Wind River seed. When the 1939 examination was made, the plantation from the Stillaguamish stock was found to be far superior to the other.

Thus we have from this seed-source study and from plantation records, evidence that there are strains (Darrington, Granite Falls, Palmer, and Gates) of Douglas fir that make superior growth in their own environment and also over a considerable range; others (Carson and Wind River) that make poor growth in their own environment and also over the range of country tested; others (Benton and Santiam) that make good growth in a particular environment or locality and very poor in other environments; and still others (Lakeview and Fortson) that made average growth over a considerable range. These wide variations in strains all occurred within the progeny from only eighteen seed sources (13 in the study and 5 mentioned in the last two paragraphs) that were selected at random without any special effort to obtain different strains. Some of the seed-source areas are located within a few miles of each other. This is positive evidence of the existence of good and bad strains as well as some indication of the frequency with which they occur right here in the Douglas fir region of western Washington and Oregon. The study by no means tells where the best or poorest strains grow since it does not even sample the best and poorest growing sites; it merely indicates the variation that exists between the points sampled and emphasizes the importance of care in selecting seed for reforestation purposes.

Progress Toward Better Douglas Fir Seed Sources

The need for securing the right tree seed for a given site has long been recognized by foresters. The establishment of the study of seed from known sources started by the U. S. Forest Service in 1911 and reported by Munger and Morris (46) in 1936, and just summarized in this publication, was the first step in that direction in the Douglas fir region. About 1930, the Long-Bell Lumber Company (40), Forestry Department, under the direction of John B. Woods, Sr., published a climatic summary of the Northwest in the form of small-scale maps for the guidance of seed purchasers. Woods defined six seed-collecting zones. J. F. Kummel in the U. S. Forest Service periodically set up rules for guidance in seed collecting based on latitude and altitude. The U. S. Department of Agriculture seed policy, set up in 1939 and reported on page 52, served as a general guide. About 1942 Munger divided the Douglas fir region into nine "provenances" that he considered sufficiently homogeneous climatically; they were based on weather records and his own personal knowledge of the region. These provenances were placed on a map and published in 1944 (36).

Dr. C. A. Schenck (57) in 1939 published lengthy records to guide in the use of Douglas fir in European plantations.

Currently the U. S. Forest Service, the States of Washington and Oregon, the Nisqually Nursery, conducted by the West Coast Lumbermen's Association, and other nurseries are making concerted efforts to obtain seed from the immediate vicinity of their customers' planting site.

These developments are helpful but more detailed information is necessary to assure best results. Climatic and soil requirements vary between species and between strains of one species, and strains vary under seemingly similar climatic conditions. The selection of a proper seed source, therefore, requires not only a knowledge of climate, but a knowledge of growing conditions as well as something regarding the strain of trees growing on a particular area. This point is vital when trees are being grown as a crop and for profit. Climatic and site information is available and will follow.

LOCATION OF DOUGLAS FIR STANDS OF DIFFERENT SITE QUALITY AND NEAREST U. S. WEATHER STATIONS

Just where the best Douglas fir grows when quality, yield, and hardiness are considered, is a question to which the final answer may never be obtained. It will change from time to time along with a change in quality requirements, growing conditions, the development or discovery of new stands, and the improvement of the species; however, a great deal of general and detailed information is in existence that can be made immediately helpful in reforestation. It is the purpose of this study to make as much of that information available as possible.

The first step toward getting seed that will produce better crops is to learn where the best natural stands are located within a climatic zone similar to that of a contemplated planting or seeding area. Small patches or scattered good trees should produce seed somewhat better than average, and perhaps even better seed can be collected from larger areas where most or all of the trees are of superior quality. Nevertheless, due to the fact that Douglas fir is predominantly cross-pollinated and therefore is highly heterogeneous in its hereditary make-up, seed lots from any area, regardless of the appearance of the parent trees, are likely to contain some seed of relatively poor quality.

Site Maps[5]

With this publication will be found a generalized "site" map of the Douglas fir region in western Washington and Oregon. It is produced from the records of the Forest Survey of the Pacific Northwest Forest and Range Experiment Station. As a part of the Forest Survey, site maps of each county were made, showing—in more detail than the map accompanying this publication—where different growth rates, or sites occur. Site, in this instance, is based on the total height of dominant and codominant trees for a given age, and reflects the combined effect of growing conditions and the quality of the growing stock (or strain of seed). The highest site quality no doubt represents the best growing conditions (favorable soil and climate) plus a fast-growing strain of trees that have developed on that site through natural selection over centuries of time or many generations of tree growth. Lower sites may be either the result of poor growing conditions or an inferior strain of seed or both. Sites I to V are recognized in the Douglas fir region. Site I is represented by stands having an average total height of dominant trees of 200 feet at 100 years of age. Site V trees (the poorest) attain a height of 80 feet in a hundred years, and sites II, III, and IV are equally spaced between I and V. A further discussion of site may be found in U.S.D.A. Tech. Bull. No. 201 (42).

Generally speaking, the better sites of Douglas fir are found on the

[5] A forest "site" or "site quality" map is one that shows the zones of growth rate for a given tree species or forest type.

lower elevations, almost 90 percent of all site I trees occurring below 1,500 feet; no site I trees were found above 2,000 feet until the summer of 1946, when a 25-acre area was found at an elevation of 3,000 feet near Oakridge, Oregon. Elevation is definitely a limiting factor for the better sites but because of variation in soil and exposure, as well as climate, the poorer sites may extend all the way from timberline down to sea level. After all, the proof of site quality lies in the actual growth and yield that takes place on the ground; indices such as elevation, soil, and climate can at best only serve as a general guide.

Exposure is an important site factor in the Douglas fir region. It has been given too little attention in the past. Northerly and easterly exposures are most favorable for Douglas fir, and the largest proportion of the better sites are found on these slopes. Growth is slower and mortality of both natural and planted seedlings is greater on the hot, dry southerly and westerly exposures.

If the soil and climate of the planting site are known, the next step for a successful reforestation project is to learn where to get a seed supply. This seed source should be in a forest area having trees of the best known growth and form, and having climate and soil comparable to that of the planting site. It is not enough to look at a map and determine where the best stands (sites I and II) occur, but it is necessary to know the climate of these areas.

Weather Records

The records of U. S. Weather Bureau stations located at various points throughout the region constitute the best and practically the only source of weather information. Widely spaced as they are, the records of these stations are still of inestimable assistance in obtaining the right tree seed for a given planting site.

The site map for each state shows the location of these stations by key number and often by name. In Tables 4 and 5 are given the weather data that are important to tree growth for each number or station.

These data are given in the tables insofar as they were available. The period of weather records for the stations varies from two to sixty-five years, and some stations, after having been in operation for a period of years, have been discontinued.

The weather data in the tables were taken from U. S. Weather Bureau records in the U.S.D.A. Yearbook for 1941, *Climate and Man,* and from other published summaries and current file records of the Weather Bureaus at Portland, Oregon, and Seattle, Washington.

Thus by the use of the map and table it is possible to locate areas of favorable growth under a fairly wide range of climatic conditions and select for a seed source that area which most nearly matches a contemplated planting site. Topographic maps[6] are available for most of the region. With a little study of the effect of change in elevation on climate and of the influence of canyons and different exposures on climate, it should be possible to evaluate climatic conditions for a considerable area in the vicinity of weather stations. A glance at the site map will show that weather stations are located in a major portion of the better growing sites. If a forester, nurseryman, or seed collector so desired, he could in that manner establish seed collection zones in areas for which weather records are available, and could then furnish seed or seedlings of the best-growing strains for varied climatic conditions.

Once local climatic conditions are known a change in elevation is the most stable guide to climatic changes at nearby points. Although temperature varies with every set of local conditions, a general rule (34) quite universally accepted for change in temperature with change in altitude (or elevation) in free air is a 1°F. drop in mean temperature for each 300-foot rise in altitude. This will serve as a usable average figure but is, of course, affected by regular winds, air drainage, canyon drafts, exposure, degree of slope, radiation, humidity, and the like. Temperature inversions frequently occur in canyons where growing conditions in a limited area are better at a higher than at a lower elevation.

No rule universally accepted for a decrease in temperature from south to north can be found. This change is so affected by oceans and air movement and topography that no general rule would apply. Average annual temperature records in Tables 4 and 5 show a drop of approximately 5°F. from Brookings on the southern Oregon coast to Tatoosh Island on the northern Washington coast, and a drop of 7°F. between Illahee, Oregon, and Darrington, Washington, two south-north stations somewhat inland. This indicates an average drop of 6°F. in an airline distance of about 450 miles, or an average drop of 1°F. for each 75 miles from south to north in the Douglas fir region. The table will show that this drop varies from station to station, depending on location and elevation; but it will serve as a general guide for temperature change in the region.

[6] Topographic maps produced by the U. S. Coast and Geodetic Survey, the U. S. Geological Survey, and by many other agencies for all parts of the region are on sale in all the larger cities. Also, more detailed weather data for the stations given and partial data for many additional stations not given are available in the U. S. Weather Bureau for those wishing to make a more detailed study of the topography and climate of any specific locality.

Table 4—*Summary of Weather Factors Important to Tree Growth*

(Douglas Fir Site Map for State of Washington shows location of these U. S. Weather Bureau Stations by number)

Weather Bureau Station No. and Name	Township	Range	Elev. *Ft.*	Temperature: Average April-Sept. °*F.*	Temperature: Average Annual °*F.*	Temperature: Absolute Max. °*F.*	Temperature: Absolute Min. °*F.*	Frost-free Days *No.*	Precipitation April to Sept. *In.*	Precipitation Av. Annual *In.*
Clallam Co.										
1 Tatoosh Island	33N	16W	50	52.0	48.1	88	7	311	21.0	83.6
2 Clallam Bay	32N	12W	70	53.7	48.0	97	8	176	18.4	80.0
3 Port Crescent	31N	8W	75	......	47.0	93	7	203	8.5	40.4
4 Port Angeles	30N	6W	98	53.6	47.7	93	–1	230	6.2	27.4
5 Sequim	30N	3W	200	55.7	48.9	99	–3	184	4.7	16.1
6 Sutherland Lake	30N	8W	500	......	......	......	......	......	10.7	54.2
7 Forks	28N	13W	375	55.6	49.3	101	–4	174	26.0	115.1
8 Snyder*	30N	11W	750	59.1	49.0	96	22	......	15.8	80.8
9 Elwha*	29N	7W	700	56.1	48.6	93	4	......	9.2	46.2
Jefferson Co.										
10 Chimacum	29N	1W	100	......	......	......	......	......	7.8	21.8
11 Clearwater	24N	12W	250	55.6	49.3	100	11	199	29.7	123.1
12 Destruction Island*	25N	13W	64	53.4	49.8	72	28	......	18.8	76.8
13 Port Townsend	30N	1W	80	56.3	50.1	94	–3	265	6.9	19.2
14 Quilcene	27N	2W	124	57.6	49.9	102	0	167	11.5	47.2
15 Spruce	27N	11W	300	......	......	......	......	......	28.2	118.3
Grays Harbor Co.										
16 Aberdeen	17N	9W	105	55.8	49.9	105	6	191	19.2	82.7
17 Canto	15N	8W	200	......	......	......	......	......	26.0	113.3
18 Elma*	18N	6W	250	57.5	49.4	104	5	184	14.0	59.1
19 Hoquiam*	17N	10W	8	55.6	50.2	96	21	......	14.0	61.8
20 Lone Tree	17N	12W	25	55.2	50.1	86	17	295	15.3	73.8
21 Oakville	16N	4W	85	58.3	50.8	105	–8	163	10.9	50.4
22 Quinault	23N	9W	210	58.3	50.9	104	11	208	30.3	126.5
23 Satsop	18N	7W	40	......	......	......	......	......	14.4	64.0
24 Olympic Tree F.	20N	7W	580	55.7	49.0	94	21	......	21.8	120.8
25 Wishkah Headwks.	21N	8W	435	......	......	......	......	......	28.8	118.8
Pacific Co.										
26 Brooklyn	15N	6W	275	......	......	......	......	......	15.3	70.2
27 Naselle	10N	9W	25	......	......	......	......	......	23.3	110.6
28 North Head	9N	11W	196	54.1	50.0	97	11	297	14.4	59.1
29 South Bend	14N	9W	50	56.8	50.8	103	4	202	19.2	83.7
30 Willapa Harbor	14N	9W	150	57.1	51.1	103	4	200	19.3	82.6
Wahkiakum Co.										
31 Cathlamet	8N	6W	476	......	......	......	......	......	17.5	80.8
San Juan Co.										
32 Olga	36N	1W	80	55.8	49.6	92	–3	229	8.2	29.0
Island Co.										
33 Coupeville	32N	1E	50	56.4	49.9	96	5	208	6.5	18.6

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Table 4—*Summary of Weather Factors Important to Tree Growth*
(Douglas Fir Site Map for State of Washington shows location of these U. S. Weather Bureau Stations by number)

Weather Bureau Station No. and Name	Township	Range	Elev. *Ft.*	Temperature				Frost-free Days *No.*	Precipitation	
				Average		Absolute				
				April-Sept. °*F.*	Annual °*F.*	Max. °*F.*	Min. °*F.*		April to Sept. *In.*	Av. Annual *In.*
Kitsap Co.										
34 Bremerton	24N	1E	7	57.5	50.7	98	14	211	7.8	36.5
35 Keyport	26N	1E	17	58.6	51.7	99	10	210	7.3	33.1
Thurston Co.										
36 Alder Dam*	15N	4E	1250	55.8	50.4	92	21	......	12.3	45.1
37 Olympia	18N	2W	69	58.3	50.8	104	−2	191	11.2	52.3
Whatcom Co.										
38 Bellingham	38N	3E	120	56.0	48.9	97	−4	186	10.3	34.0
39 Blaine	40N	1E	40	56.2	48.8	95	−9	175	11.4	41.0
40 Clearbrook	40N	4E	64	56.6	48.8	102	−4	143	14.4	47.4
41 Diablo Dam	38N	13E	891	58.5	48.5	106	−10	......	13.1	61.5
42 Glacier	39N	7E	937	55.6	46.6	101	−9	150	15.5	54.1
43 Marietta	38N	2E	10	57.4	50.0	98	−1	181	9.1	31.8
44 Mt. Baker Lodge	39N	9E	3500	......	......	86	−6	......	32.6	111.0
45 Skagit Power	37N	12E	505	60.1	50.3	109	−4	211	14.4	72.6
Skagit Co.										
46 Anacortes	35N	2E	40	57.2	50.6	95	6	231	7.9	26.6
47 Concrete	35N	8E	243	59.7	50.9	106	−1	204	15.1	60.8
48 Sedro-Woolley	35N	4E	56	......	50.4	99	−1	183	......	45.5
Snohomish Co.										
49 Arlington	31N	5E	205	......	......	......	......	......	14.2	45.6
50 Bothell	26N	5E	100	56.9	50.0	99	−2	......	10.4	37.7
51 Darrington	32N	9E	550	57.4	48.7	105	−11	145	17.2	76.0
52 Everett	29N	5E	127	56.9	50.1	91	3	213	9.9	32.5
53 Monroe	27N	6E	120	58.7	51.1	101	2	197	13.9	43.4
54 Startup	28N	9E	560	59.4	52.0	106	5	219	18.6	49.4
King Co.										
55 Cedar Lake	22N	8E	1560	56.4	48.6	98	0	210	28.8	103.3
56 Greenwater*	19N	9E	1708	53.6	44.8	102	−2	......	18.5	54.1
57 Landsburg	22N	7E	535	57.3	49.7	101	0	164	16.0	53.0
58 Lester	20N	10E	2000	56.1	47.8	103	−2	108	12.8	51.2
59 Mountain Lake	26N	7E	814	......	......	......	......	......	15.8	50.8
60 Mud Mountain*	20N	7E	1308	55.6	48.7	99	7	......	18.5	46.9
61 Palmer	21N	7E	895	57.1	49.3	102	0	194	25.9	86.0
62 Scenic	26N	13E	2224	......	......	......	......	......	17.0	75.4
63 Seattle	25N	4E	14	60.0	52.8	99	3	255	8.7	34.1
64 Seattle, U. of W.	25N	4E	114	59.1	51.9	99	10	250	8.3	32.4
65 Seattle-Tac. Airpt.*	23N	4E	379	......	50.8	90	18	......	......	41.2
66 Snoqualmie Falls	24N	8E	430	58.7	50.6	104	3	172	15.6	55.2
67 Snoqualmie Pass	22N	11E	3010	50.5	41.6	101	−17	115	20.7	94.7
68 Stevens Pass*	26N	13E	4061	49.1	39.6	95	−11	......	18.8	54.6
69 Stampede Pass*	21N	11E	3962	48.8	39.5	88	5	......	25.5	83.9
70 Vashon Island	23N	3E	48	57.6	50.5	96	5	223	9.5	41.6

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Pierce Co.										
71 Buckley	19N	6E	685	57.8	50.4	102	5	197	14.8	46.3
72 Carbon River	17N	7E	1716	......	46.6	96	−6	......	......	65.4
73 Headworks	15N	4E	1250	55.4	48.2	99	−8	142	12.3	45.1
74 Longmire	15N	8E	2761	53.3	44.6	105	−9	134	18.6	76.9
75 McMillan Res	19N	5E	579	......	......	97	6	......	......	......
76 Mineral	14N	5E	1440	......	......	......	......	......	16.9	75.7
77 Minter Creek	22N	1W	17	......	......	......	......	......	18.2	54.2
78 Puyallup	20N	4E	100	57.4	50.8	99	−2	177	10.0	38.3
79 Paradise Inn	15N	8E	5550	46.0	38.4	92	−20	79	25.0	98.2
80 Sumner	20N	5E	110	......	......	94	−7	158	11.1	43.0
81 Tacoma	20N	2E	109	57.4	50.3	98	7	250	9.8	40.4
Mason Co.										
82 Cushman Dam	22N	4E	790	62.2	51.0	104	3	209	19.0	95.6
83 Grapeview	21N	2W	30	59.4	51.8	102	10	209	10.3	51.5
84 Shelton	20N	3W	22	59.4	51.6	104	6	193	12.3	63.9
Lewis Co.										
85 Centralia	14N	2W	182	58.8	51.4	105	−16	173	11.0	44.8
86 Kosmos	12N	5E	775	58.3	50.4	105	−15	147	15.1	56.8
87 Ohanapecosh	14N	10E	2004	......	......	......	......	......	13.8	53.3
88 Packwood*	13N	9E	1060	60.1	......	108	2	......	10.7	50.7
89 Rainbow Falls	13N	4W	301	......	......	......	......	......	11.0	44.2
90 Randle	12N	7E	912	......	......	......	......	......	12.9	57.0
Cowlitz Co.										
91 Ariel	6N	2E	224	......	......	......	......	......	15.0	65.4
92 Castle Rock	9N	2W	300	58.6	50.8	105	−13	182	12.5	56.7
93 Kalama	6N	1W	300	......	......	......	......	209	15.6	64.2
94 Kelso	8N	2W	254	......	......	......	......	175	10.2	38.3
95 Kid Valley*	10N	1E	690	55.8	48.1	100	13	......	16.4	50.3
96 Longview	8N	2W	21	59.0	51.5	105	−20	171	10.6	40.6
97 Yale	6N	3E	300	......	......	104	3	183	19.7	93.7
Clark Co.										
98 Battleground*	3N	2E	295	57.9	50.7	105	1	......	13.1	45.9
99 Vancouver	2N	1E	100	61.0	52.8	105	−10	226	9.4	37.3
100 Yacolt	5N	3E	737	......	......	......	......	136	17.6	75.8
Skamania Co.										
101 Cougar	7N	4E	550	......	......	......	......	......	24.2	117.7
102 Spirit Lake	9N	5E	3200	50.2	42.4	96	−8	......	20.1	86.8
103 Prindle	1N	5E	200	61.5	53.3	104	7	220	16.2	66.8
104 Peterson's Ranch	7N	5E	596	......	......	......	......	......	23.5	114.6
105 Wind River	4N	7E	1130	57.6	48.4	107	−13	134	16.5	86.7

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Table 5—*Summary of Weather Factors Important to Tree Growth*

(Douglas Fir Site Map for State of Oregon shows location of these U. S. Weather Bureau Stations by number)

Weather Bureau Station No. and Name	Township	Range	Elev. *Ft.*	Temperature: Average: April-Sept. *°F.*	Temperature: Average: Annual *°F.*	Temperature: Absolute: Max. *°F.*	Temperature: Absolute: Min. *°F.*	Frost-free Days *No.*	Precipitation: April to Sept. *In.*	Precipitation: Av. Annual *In.*
Clatsop Co.										
106 Astoria	8N	9W	230	57.0	51.2	97	10	273	17.6	76.3
107 Ast. Exp. Station	7N	8W	50	56.9	50.3	104	11	275	15.6	66.1
108 Northrup Creek	6N	6W	540	56.3	50.6	101	2	......	14.4	62.4
109 Jewell	5N	6W	700	57.3	50.2	103	–4	166	14.4	69.3
110 Seaside	6N	10W	10	56.4	52.0	100	12	......	17.3	75.9
Columbia Co.										
111 Clatskanie	7N	4W	80	58.9	51.2	103	9	......	11.7	53.2
112 Doraville	6N	3W	750	57.0	49.4	101	–5	197	11.5	48.4
113 Vernonia	4N	4W	748	57.5	50.0	104	1	188	11.5	50.6
Tillamook Co.										
114 Cloverdale*	4S	10W	60	56.5	51.6	98	15	......	20.6	78.5
115 Glenora	1N	7W	575	56.6	49.1	106	3	140	26.8	129.5
116 Nehalem	3N	10W	10	......	......	......	......	......	27.3	109.3
117 Tillamook	1S	9W	26	55.0	50.6	101	0	182	22.2	94.0
Washington Co.										
118 Forest Grove	1N	3W	220	60.2	51.7	108	–15	164	9.3	46.2
119 Hillsboro	1N	2W	203	60.3	51.8	107	–2	......	7.5	36.3
Multnomah Co.										
120 Portland	1N	1E	30	61.1	53.1	105	–2	263	9.8	41.6
121 Bonneville	2N	7E	85	62.6	53.4	107	7	......	14.7	65.7
Hood River Co.										
122 Cascade Locks	2N	7E	100	61.7	52.4	107	–9	217	16.0	76.2
123 Hood River	3N	10E	300	60.3	50.3	106	–27	183	5.3	30.6
124 Parkdale	1S	10E	1740	56.7	47.1	101	–22	143	6.5	39.5
Clackamas Co.										
125 Cazadero	3S	4E	414	60.3	52.7	109	–6	194	14.6	55.2
126 Government Camp	3S	8E	3890	49.1	42.3	96	–16	......	22.3	84.6
127 Headworks	2S	5E	747	59.0	50.5	110	–2	204	21.8	78.1
128 Intake	6S	7E	2000	64.0	55.4	104	–2	......	12.7	49.6
129 Miramonte Farm	4S	1E	200	59.6	51.6	101	–11	202	10.9	42.7
130 Molalla	5S	2E	100	......	......	......	......	......	12.3	41.7
131 Sundown Ranch	7S	2E	2350	54.9	48.5	......	......	......	18.4	69.8
132 Three Links	5S	6E	1135	59.6	51.1	107	3	198	15.2	60.0
133 Timberline Lodge*	3S	9E	6000	48.1	37.1	......	......	......	29.6	76.8
134 Zig Zag	3S	7E	1435	57.0	48.8	......	......	......	20.3	76.3
Marion Co.										
135 Detroit	10S	5E	1450	57.5	49.0	......	......	166	15.7	70.5
136 Mt. Angel	6S	1W	500	61.0	52.9	106	–15	218	11.5	47.5
137 Salem	8S	2W	195	60.5	53.3	108	–6	213	8.8	36.4
138 Silver Creek*	8S	1E	1340	56.4	49.4	......	......	......	19.4	71.8

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				Average		Absolute				
				April-Sept. °*F.*	An-nual °*F.*	Max. °*F.*	Min. °*F.*		April to Sept. *In.*	Av. An-nual *In.*
Yamhill Co.										
139 McMinnville......	4S	4W	150	60.2	52.6	110	–24	174	8.5	42.9
140 Spring Glade Acres*	2S	5W	900	......	......	......	......	......	9.3	60.9
Polk Co.										
141 Dallas...........	7S	5W	325	59.1	50.9	......	......	......	8.6	40.6
142 Falls City.........	8S	6W	550	58.7	51.2	106	–5	165	10.8	69.5
143 Grand Ronde.....	6S	8W	360	......	......	......	......	......	10.2	52.5
144 Valsetz...........	8S	8W	1150	56.7	50.0	......	......	......	23.2	114.3
Lincoln Co.										
145 Cascade Hd. Exp. For.*...........	6S	10W	50	57.0	48.0	94	15	......	20.9	90.0
146 Newport..........	11S	11W	155	54.2	50.9	100	1	248	16.8	65.8
147 Toledo...........	11S	10W	200	56.8	51.8	102	8	195	16.1	75.6
148 Tidewater*........	13S	10W	30	59.8	53.3	......	......	......	20.2	88.7
Benton Co.										
149 Alpine Monroe....	14S	5W	400	59.2	52.0	102	–1	197	8.6	49.5
150 Corvallis..........	11S	5W	266	60.2	52.4	106	–14	191	6.9	39.1
151 Summit..........	11S	7W	720	......	......	......	......	......	12.4	62.4
Linn Co.										
152 Albany...........	11S	3W	212	60.6	52.8	104	–15	212	8.1	41.1
153 Cascadia..........	13S	3E	796	59.5	51.2	101	2	185	17.0	62.2
154 Lacomb..........	11S	1E	610	59.8	52.0	......	......	......	12.6	52.4
Lane Co.										
155 Black Butte.......	23S	3W	1200	56.6	49.2	100	5	142	12.2	49.3
156 Canary...........	19S	11W	50	56.6	52.0	......	......	......	14.8	74.7
157 Cottage Grove....	20S	3W	822	59.0	52.0	105	–7	166	9.9	43.0
158 Eugene Airport....	17S	4W	364	59.7	52.3	104	–4	205	9.3	37.9
159 Leaburg..........	17S	1E	675	61.3	52.5	......	......	97	14.2	56.8
160 McKenzie Bridge..	16S	5E	1372	57.4	50.1	108	–3	97	15.7	68.2
161 McCredie Springs..	21S	4E	2121	57.1	......	......	......	......	13.4	.....
162 Oakridge.........	21S	3E	1313	61.7	53.2	110	0	187	9.9	38.2
163 Rujada...........	21S	1E	......	......	......	......	......	......	13.0	48.3
Klamath Co.										
164 Cascade Summit...	23S	6E	4841	49.8	41.0	107	–16	......	10.6	49.6
165 Crater Lake.......	31S	6E	6400	46.7	38.6	100	–20	......	13.2	58.3
Douglas Co.										
166 Drain............	22S	5W	302	60.3	53.0	107	–1	187	8.0	43.5
167 Diamond Lake....	27S	6E	......	47.3	......	......	......	......	11.4	49.1
168 Elkton...........	22S	7W	185	61.3	54.8	......	......	......	9.8	60.2
169 Glendale..........	33S	6W	1441	60.1	52.7	109	11	142	7.3	37.8

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				Average		Absolute			April to Sept. *In.*	Av. An-nual *In.*
				April-Sept. °*F.*	An-nual °*F.*	Max. °*F.*	Min. °*F.*			
Douglas Co.—Cont.										
170 Gardiner	21S	12W	50	56.5	52.5	102	16	255	17.0	78.7
171 Riddle	30S	6W	703	61.1	53.6	110	3	200	6.2	28.5
172 Roseburg	27S	6W	479	61.3	53.4	107	–6	234	7.1	32.9
173 Reedsport	21S	12W	50	57.4	52.3	......	......	......	14.5	73.3
Coos Co.										
174 Bandon	29S	14W	12	55.5	51.8	89	14	......	13.6	65.9
175 Coquille L. H.	28S	14W	12	......	......	......	......	......	10.4	51.6
176 McKinley	27S	10W	140	59.0	52.1	107	6	187	12.6	65.7
177 Marshfield	25S	13W	100	56.0	51.8	100	16	197	12.6	54.8
178 North Bend	25S	13W	203	56.1	51.2	......	......	......	12.9	51.9
179 Powers	31S	12W	300	60.0	54.4	......	......	......	9.9	57.7
180 Sitkum*	28S	10W	......	56.4	51.4	......	......	......	16.2	91.7
Curry Co.										
181 Brookings	41S	13W	162	56.3	53.0	100	17	269	15.1	74.6
182 Gold Beach	36S	14W	69	55.4	52.3	98	20	238	13.6	75.7
183 Illahe	34S	11W	300	64.0	55.4	109	15	......	12.9	102.4
184 Port Orford	33S	15W	270	56.0	49.8	90	15	286	13.7	70.1
Josephine Co.										
185 Grants Pass	36S	5W	940	62.6	53.6	114	0	132	5.4	30.0
186 Sexton Summit	34S	6W	3836	56.5	48.2	......	......	......	6.5	29.5
187 Waldo	40S	8W	1650	59.7	50.6	109	–1	155	8.8	49.8
188 Williams	38S	5W	1385	60.2	52.0	107	3	145	5.0	31.8
189 Wolf Creek	33S	6W	1274	60.6	52.3	110	–3	164	6.7	39.2
Jackson Co.										
190 Ashland	39S	1E	1956	61.4	52.7	106	–1	182	5.9	20.0
191 Fish Lake	36S	4E	4687	53.2	44.3	100	–15	......	8.1	41.1
192 Hillcrest Orchard	37S	1W	1595	63.0	52.3	107	–9	163	4.9	17.6
193 Jacksonville	37S	2W	1640	62.6	52.8	106	–1	190	5.5	24.7
194 Lake Creek	36S	2E	2000	60.3	52.0	107	0	152	7.5	36.8
195 Modoc Orchard	36S	2W	1270	63.1	53.4	110	–8	163	4.4	20.6
196 Medford	37S	2W	1314	63.9	53.8	110	–10	161	4.5	16.5
197 Prospect	32S	3E	2473	58.2	49.6	105	–12	108	8.3	39.0
198 Siskiyou Summit	40S	2E	4480	56.7	46.0	100	–5	......	5.9	23.6

* Based on five-year record or less.

INTRODUCTION OF A SUPERIOR BUT UNPROVEN STRAIN OF SEED

"Source of seed is second in importance only to choice of species in reforestation practice," is Rudolf's (55) introduction to the "Source of Seed" section of the U. S. Forest Service Seed Manual.

Proof has been established of the existence of varied strains of Douglas fir in western Washington and Oregon, and that they may be superior, inferior, or average. It has been established that strains of Douglas fir may have rather specific climatic limitation, and also that local strains cannot be planted outside the area to which they are adapted with positive assurance that they will make maximum or satisfactory growth or yield in the new location. It has also been demonstrated that Douglas fir when moved any considerable distance from point of origin may be more or less subject to disease than in its own home locality.

The site maps of the Douglas fir region of Washington and Oregon that accompany this report show where the various quality stands are found over areas of considerable size. Also, the maps show the location of the nearest established United States Weather Bureau stations. Tables 4 and 5 show climatic factors that are most important for tree growth in the locality of these stations. With this information available, and with soil and the form of the parent tree considered, experiments on plantations indicate there are reasonably good chances to secure seed that will produce superior plantations. The planter has every right to expect as good a stand or better resulting from his planting than was on the land originally.

The cost of obtaining the right seed for a given site may be no greater than the cost of the wrong seed, but even if it were greater, the difference should never be enough to become a limiting factor. If Douglas fir seed in normal times costs $5.00 a pound, seed to produce 680 seedlings per acre would cost about twenty cents, or approximately one or two percent of the total planting cost. Even if getting the right seed doubled the seed cost, it would be only a small fraction of the total cost of production. Therefore, it is safe to assume that the matter of cost can be ruled out as preventing the use of the right seed for an area. There remain the problems of selecting a superior strain and finding ways and means of working it into the stand without danger of loss from unknown site factors, and without going through the costly, time-consuming process of field testing.

The most positive assurance of getting a stand equal to the one that was on the land previously is, of course, to secure seed from the immediate vicinity. That procedure, however, offers no chance for improvement in future crops; furthermore, as pointed out under the section on geographical races (or local strains), it is always possible that a strain may be found which may be more desirable than the one growing in the immediate vicinity. Even though the indications are that such a strain is available, it is extremely hazardous to use the unproved seed for the entire reforestation job on a given area. Where planting is necessary, the cost of planting, plus interest, amounts to half of the final cost of timber production in most plantations. If an introduced stock for some unknown reason proves to be unsatisfactory for a site, this condition usually does not show up for a period of five to thirty years, or at any rate until it is too late to correct the error. As a result, the planting project must be operated at a loss and becomes a failure.

Use of a Superior Strain in Planting

Fortunately, however, there is a lucky circumstance in the process of reforestation that offers a very good chance of securing a better crop with little or no chance of securing a poorer crop than existed on the land in its virgin state.

The process is this: ordinarily on an 8 x 8 plantation (standard spacing for planting in the Douglas fir region) 680 trees are planted to the acre if there is no unplantable surface. On the average not more than 150 to 200 of these trees can be expected to become crop trees and live through to a rotation age of 60 to 100 years. In the course of growth from seedlings to harvest size, the more vigorous Douglas fir trees have a habit of asserting dominance early in their growth. Five hundred of the 680 trees per acre are thus suppressed and crowded out of the stand in the process of natural selection over the period of development to the rotation age. The heavy stocking or crowding-out process is desirable to shade out lower limbs and cause natural pruning. The most vigorous trees in most stands become the dominant and codominant trees and form the ultimate crop trees.

This being true, it should be possible to produce stock of which half is from local seed and half from an introduced but unproved strain that promises to produce a superior crop. If the introduced strain proves to be superior in growth and development, and if no unknown factor of climate or soil develops that militates against it, then the best trees from this introduced strain should develop into the dominant and codominant trees in the stand. Trees from the local strain would then fall into the intermediate and suppressed crown classes; they would fall out in the process of natural selection, or would be harvested in the form of thinnings and stand improvement, leaving the superior strain in possession of the site.

On the other hand, if there was some unknown factor of site that proved unfavorable to the introduced strain, then the trees from this strain would in all probability fall into the intermediate or suppressed crown classes. The most vigorous trees from the local strain would then develop into the dominant and codominant components of the final stand. Thus the operator would have a final crop at least as good as the stand grown on the land originally, with only a small additional cost for the introduced strain of seedlings. This procedure was recommended by Righter (53) for the introduction of costly hybrids into ponderosa pine plantations; it has also been used by European foresters.

The production of stock, half from local seed and half from an introduced strain, can be accomplished in two ways: either by thoroughly mixing the seed before it is planted in the seed bed, or by planting the two strains of seed separately and mixing the seedlings during the planting operation. Mixing the seed is by far the simpler and cheaper method; however, some authorities feel that this may eliminate many of the trees of the introduced strain through crowding and other conditions in the nursery beds. There is also a likelihood that many of the seedlings from the local strain would make fast early growth because of accidentally securing more space, fertilizer, or moisture in the seed bed. They would thus become part of the dominant and codominant trees in the stand; but if they were hereditarily poor, they would fall back as the stand progressed and lower the ultimate yield. On the other hand, if the seedlings were raised separately there could be definite assurance that an equal number of each strain could be distributed over the area in the process of planting.

If it becomes necessary to bring in all seed from a somewhat distant point, it is always wise to mix two or more slightly different lots, on the chance that one lot will be better suited to the site than the others and will produce the dominant and codominant trees.

Adding a Superior Strain to Natural Regeneration

Natural regeneration of Douglas fir on a favorable site is of course the best assurance obtainable for a stand of timber equal at a given age to the one removed from the area. But, as previously stated, using this regeneration overlooks the possibility that a strain of trees can be found to give better growth and development on the area. Nevertheless, it is a worthy objective, for the natural regeneration may prove to be a more profitable first crop than a superior planted stand when labor costs and interest charges for planting are computed. (Table 1).

For the same reason, a planted forest must produce a superior stand if it is to be as profitable as natural stands, at least for the first generation.

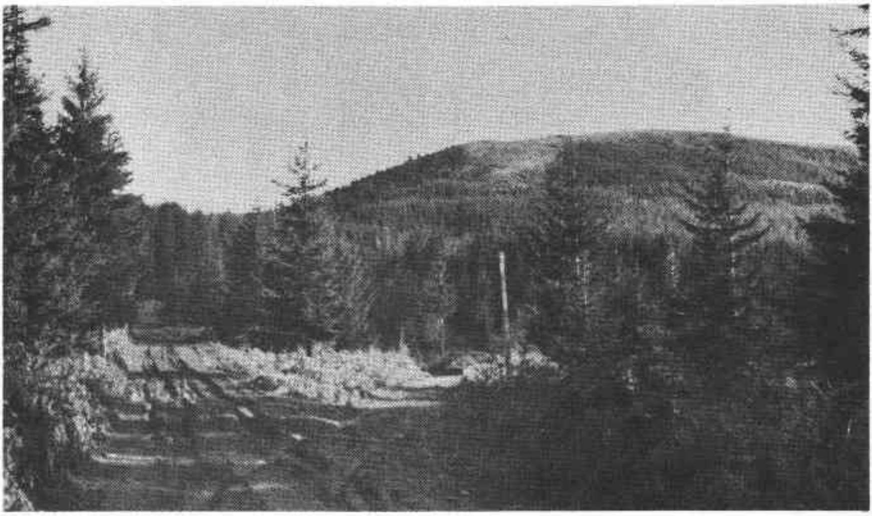

Fig. 8A—This area on Hebo Mountain was planted in 1912 to 1914 and photographed in 1943. The foreground is approximately 800-foot elevation and the ridge top approximately 3,000 feet. It was all planted with Douglas fir planting stock raised from low-altitude seed. (See close-up in next two pictures.)

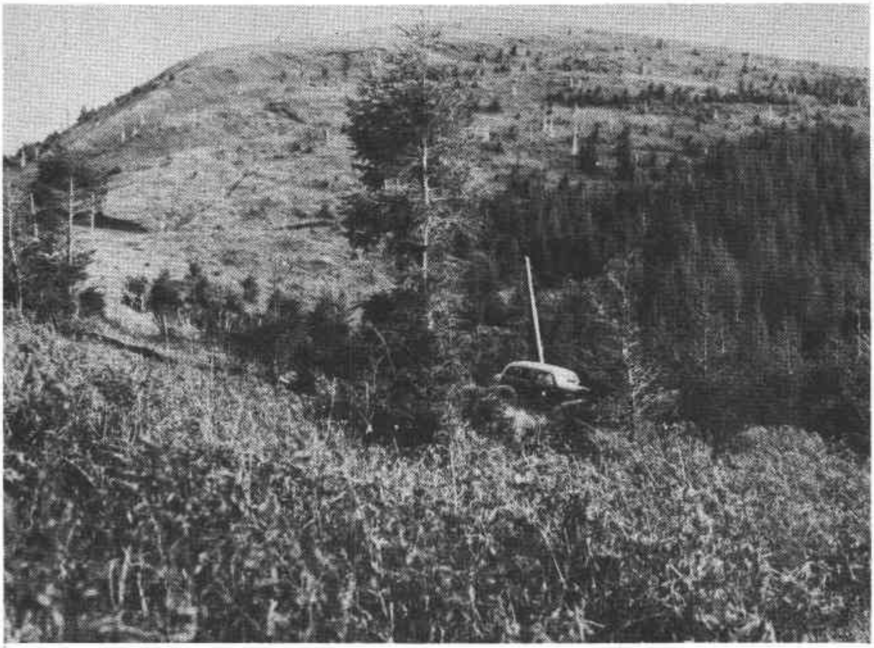

Fig. 8B—Upper portion of previous picture showing scattered stunted trees at the 2,500- to 3,000-foot elevation. Planting stock produced from seed collected from below 1,000-foot elevation. Lone survivor making vigorous growth in center of picture shows that fir from right stock can make good growth on this site. It is suspected of being a volunteer from some local seed source rather than a hardy individual from the original planting stock.

Fig. 8-C—Lower part of plantation; photo taken at approximately the 800-foot elevation. A 30-year-old plantation with trees almost piling size grown from the same low-altitude stock as the previous picture.

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This can and should be accomplished: first, by getting a strain of seed superior from the standpoint of yield and quality (Fig. 10); second, by better distribution of stems; third, by more prompt restocking; and fourth, by less loss of growth through overstocking in some spots and understocking in others.

Uneven or understocked stands, whether they follow natural regeneration or planting, are most likely to be unprofitable even though they approach normality as they grow older. Such stands are likely to produce not only less volume but poorer quality of material because of heavy limb development and the absence of natural pruning.

A real opportunity for crop improvement and profit lies in combining artificial and natural regeneration, either by planting to "fill-in" understocked stands or by adding to stands that are restocking too slowly. It comes about in this manner: if a superior strain of trees is available for a given area, planting a number of seedlings equal to or somewhat larger than the number of final crop trees should not require more than a third (225 trees) of the normal number of planted trees per acre. This should not cost more than half of normal planting costs. The benefits of such planting (of natural regenerating areas) should be as follows: first, prompt restocking might reduce by eight years the normal rotation age; second, superior strain plus better distribution and more adequate restocking should produce a better yield of better quality; third, if the introduced strain is really superior, and will reproduce, it should constitute the final crop and thus leave the superior strain to provide natural reproduction for future generations.

High and Low Altitude Seed

The principle of mixing seed or stock can also be employed to secure growing stock that will meet the requirements of a wide range in altitude or variation in exposure. Planting sites are frequently rugged and steep; changes in altitude (Fig. 7A) and aspect are too frequent and too great to permit using a separate stock correct for each altitude and aspect. For example, if range in altitude varied from 500 to 1,500 feet, it should be possible to produce half of the stock from the seed of a 700-foot elevation and the other half from seed of a 1,300-foot elevation. It is reasonable to expect that when this mixture is planted on the site the seedlings from the seed gathered at a 700-foot elevation will produce the dominant and codominant trees for the lower levels of the planting site. Similarly the seedling from the seed gathered at a 1,300-foot elevation should produce the crop trees for the higher levels of the plantation.

EXISTING RULES AND LAWS FOR THE SELECTION OF TREE SEED

The need for care in seed selection has been shown but ways and means of doing the job have not been worked out. Based on experience with plantations and a few actual tests, some general and some specific rules have been set up in America for the procurement of tree seeds for reforestation; and in Europe some laws have been passed governing seed collection and sale. Provenance rules and laws often cover form and growth rate as well as climatic requirements.

European countries (6), except England, have all adopted some form of compulsory or voluntary control of seed origin for reforestation. The most restrictive was the German Forest Seed Law (Forstliches Artgesetz) of 1934. It resulted in all seed being sold in certified sealed packages with the history of origin on the outside. It required that seed be used within its natural range, and that no inferior trees or stands, capable of bearing pollen, be within 300 meters (984 feet) of certified seed trees. Ten "site races" of Scots pine and several of Douglas fir were recognized.

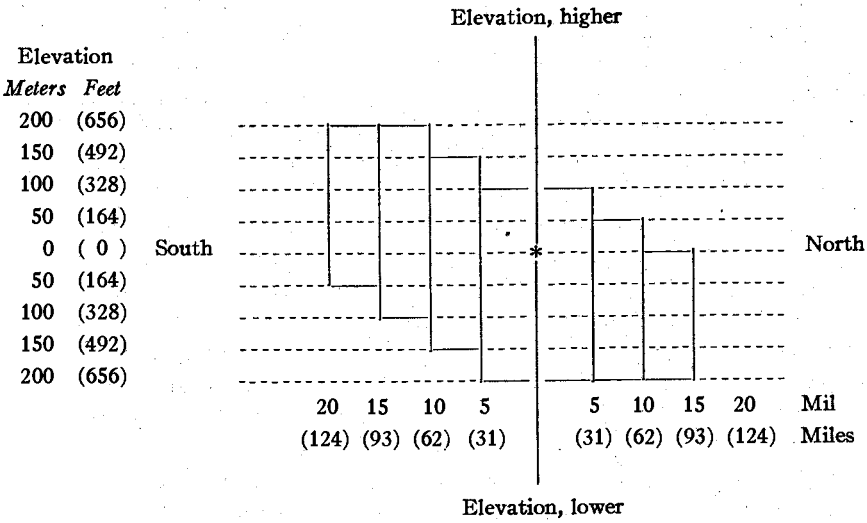
Complete details of the German law and a review of all compulsory and voluntary forest seed control in European countries, together with a note on United States and Canadian procedure, are contained in an article by Baldwin and Shirley (10). They indicate that most European countries are aware of the need for seed control and certification and are doing something about it.

Sweden has been divided into forest zones based on mean isotherms of approximately 1°C. for June to September temperatures (9). The use of seed from more than one zone distant in either direction is not recommended. Each year a bulletin (61) is published showing the forest flowering and seed crop by these 1° zones, and often divisions are shown within these zones. Swedish foresters have worked out a diagram that serves as a guide for seed collecting and planting. It gives attention to altitude as well as latitude, setting up different scales for different species and for the northern and southern part of the region. Langlet (37) explains the system in detail. Fig. 9 is a diagram of limitations set up for Scots pine in northern Sweden. It shows the distance from point of origin that seed can be planted, either up or down or to the north or south. The same is shown for location of the seed source for a given planting.

Jensen (32) has outlined Sweden's plans to establish so-called "Elite" seed plantations from selected trees to provide a satisfactory seed supply. In these areas inferior individuals are eliminated so that there will be no cross pollination with poor stock and seed can be certified as to growth and form (Fig. 10) as well as to climatic tolerance.

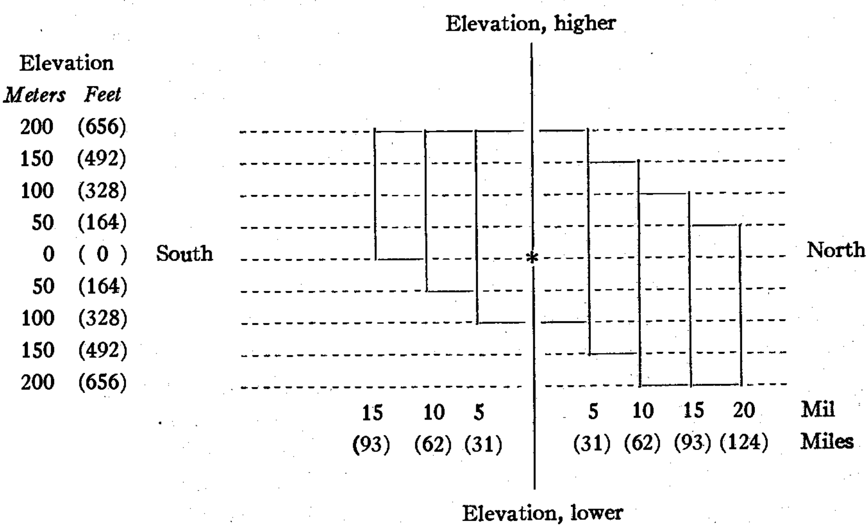
Fig. 9—*Regulation for Scots Pine Seed Sources in Northern Sweden*

A. Distance from point of origin and elevation at which seed from a given location can be used.



* Point of seed origin.

B. Allowable location of seed source for planting at a given location.



* Location of planting site.

Word has just been received outlining the most recent (1947) system of seed procurement in Norway.[7] The country is divided into seed districts called "fylkes" and these are subdivided according to latitude and elevation. In Norway, foresters recognize 7 elevation zones of 100 meters each. Seed can be used one zone up or one zone down and 2° latitude north or 2° south. Seed is collected only from certified stands. Most seed is collected and extracted by the government and sold at cost. All seed must be certified as to date collected, place or origin, soundness, and collector's name. When each major lot is extracted a sample is sent to the Department of Agriculture for certification. All importations of tree seed are under control of West Norway Forest Experiment Station.

The U. S. Department of Agriculture in May, 1939, established a "Forest Seed Policy" for the Forest Service and the Soil Conservation Service. It required that only seed of known origin be used, that record of lot number, year, species, locality and elevation of origin, and proof of origin be furnished when purchases were made. Local seed, that is seed collected within 100 miles and differing less than 1,000 feet in elevation, was to be used when available. When outside seed must be purchased it was to be obtained from an environment as similar as possible.

Fowells (23) at the California Forest Experiment Station has subdivided California's forest regions into 13 seed-collection zones based on type and site. Seed from the appropriate zones is used in the reforestation program on the national forests of California.

The U. S. Federal Seed Act of August, 1939, governs vegetable and crop seed certification only and does not extend to forest tree seeds.

To date New York State and Georgia have enacted forest seed laws and the Minnesota State Highway Department has set up rules for guidance in purchasing seeds. Just how effective these measures are is not known. A record of forest seed regulations in other states could not be found.

SUGGESTED RULES OR LAWS FOR GOVERNING TREE-SEED COLLECTION IN THE UNITED STATES

Experiments in this country and regulations observed in other countries where forests are raised as a crop have demonstrated beyond question the necessity for getting the best seed for a given site as well as the need for seed certification that will provide the forest grower with some sort of guarantee of growth rate and quality. Just how this can be done in the United States is the problem. Plans for certification of tree seed have been proposed (page 50) but no further progress has been made.

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[7] Opsahl, W., Oslo, Norway. Data furnished by personal letter.

Ways and Means of Seed Certification

Seed zones are determined by climate and soil and do not coincide with state boundaries; therefore, type or region-wide rules are essential. They can be set up by private seed companies, by a voluntary certification of seed by companies registering with some public association, state or federal agency, or by being placed under a federal control like the Federal Seed Act of August 9, 1939 (U. S. Department of Agriculture Service and Regulatory Announcement No. 156) that governs vegetable and crop seed certification. One or the other of these forms of regulation is used in the European countries; if not a complete success, they are at least a great improvement over no regulation at all.

There is one established agency in the United States whose sphere of activity could very easily be extended to provide for forest-seed certification. This agency consists of the nurseries established under the Clarke-McNary Act of June 7, 1924, for the purpose of furnishing tree seeds or seedlings at a low cost to farmers. The United States Secretary of Agriculture is authorized to cooperate on a 50-50 basis with states in the support of these nurseries. They are operated by the states and are established and functioning in 41 states and two territories.

It may require an act of Congress to amend the law, but this could be done so that Clarke-McNary nurseries could furnish tree seed for reforestation as well as tree seedlings for farmers. They could either do the complete job of collection and sale of seed or provide the facilities under which seed collected by private parties could be certified as to place of origin, form of parents, climatic limitation, and percent of viability. Since the job would be handled jointly by state and federal governments through an already established agency, this use of the nurseries appears to be the most logical solution of one of the most complicated and vital problems in the American reforestation program.

Specific Rules Suggested for Douglas Fir Seed Collection

The fixed hereditary characteristics and the climatic limitations of specific strains of Douglas fir vary; moreover, they are not definitely known. Neither is the location known of superior strains for specific climatic zones. Until these facts are determined by research only tentative rules, subject to change, can be set up to guide seed collection.

A good stand and well-formed trees (Fig. 10) growing in a climate like that of the planting site is the all-important general rule for selecting a seed source; and on irregular terrain found between the Cascade Range summit and the Pacific Ocean, climate is not determined by elevation and latitude alone. Climatic records and topography must be correlated. A set of suggested rules or limitations for Douglas fir seed collection that is believed safe for the coast region, based on the best information available, is as follows:

1. Collect seed within a hundred miles north or south of planting site if at a similar elevation.

2. A 500-foot rise or drop in elevation (from planting site) is allowable if seed source is not more than 10 miles to the north or south.

3. For each additional 10 miles north of planting site the allowable elevation for seed collection is reduced by 50 feet, up to 100 miles north.

4. For each additional 10 miles south the elevation may be increased 50 feet, up to 100 miles south.

5. In a rough, broken country climate should guide more than distance or elevation. Average annual temperature of the seed source should be within 2° F., plus or minus, and frost-free period should be similar to that of the planting site.

6. The seed-source stand should be thrifty and making average or better than average growth for the locality.

7. Individual seed trees should be of good form and should not be excessively limby (Fig. 10).

Those rules are limitations, not optimum conditions, under which to collect seed. It is an accepted rule that, other things being equal, rate of growth is proportional to length of growing season, also that practically all species can be safely moved a short distance either north or south of their native location except at the upper and lower extremities of their range. Out of these two facts has developed the rule that for optimum growth, associated with satisfactory survival and thrift, seed should be collected just a little south or at a slightly lower elevation than the planting site. In other words, collect seed from a slightly warmer climate to take advantage of the habit of a longer growing season but yet not so warm that the tree is likely to be injured by minimum temperatures on the new planting site.

GENETIC IMPROVEMENT OF EXISTING STRAINS OF DOUGLAS FIR

Thus far this publication has dealt with the segregation of varieties and geographical races of the wild population of Douglas fir. It has evaluated their variations and discussed ways and means of employing in a reforestation program the best local strains for specific sites.

from Better Seed

The next logical step is the genetic improvement of existing strains in such hereditary traits as hardiness, growth rate, and quality. Although it requires future study, this can be done: first, by the selection of the best wild strains (Fig. 10) for placement in plantations which will in turn produce seed having both parents of good stock; second, by the production of new types through hybridization and vegetative propagation; and third, though primarily a research tool at present, by the production of new forms or virtually new species through induced changes in the normal number of chromosomes or through the discovery of similar natural changes.

Obtaining seed from the best local strains is the quickest and only immediately available means for obtaining improved stands in reforestation. Genetic improvement of the species, though not less important, is by its nature a long time study. Some phases of species improvement can be accomplished by short periods of study (1 to 5 years), but in the main the improvement of forest tree species requires continuity over a long period of years. It should not be attempted except by an institution or organization having funds, facilities, and trained personnel continuously available.

Selection

A genetic improvement through selection has been studied by forest tree breeders for many years. It involves the use of seed from the best trees of the best existing strain or strains (Fig. 10) to produce stock for plantations. In turn, seed from these plantations, either with or without the elimination of inferior individuals before seed-producing age, is reasonably certain to result in improved Douglas fir stands. This process is being done elsewhere and with other species, for example, the German seed law explained on page 50 and the Swedish "Elite" seed plantations noted on page 50. Since pistillate flowers of a Douglas fir receive their pollen from staminate flowers of another Douglas fir tree, there is certain to be cross-fertilization with other good trees in the plantation. Consequently, the line degeneration with attendant loss of vigor, which usually accompanies self-fertilization, is automatically and naturally avoided. If self-sterile but superior individuals of Douglas fir are placed side by side in plantation so that they cross-pollinate, the best characteristics of both parents are just as likely to show up in a limited number of the progeny as if the female flowers had been hand pollinated. However, the male parent would not be definitely known, and the cross could not be recorded and repeated with certainty.

Trees of inherently superior form and vigor may not be easily recognized. However, local strains of superior growth are known to exist in different climatic ranges and on different soil types. It is not too soon for all agencies concerned to seek out these superior strains for their seed sources and isolate superior natural or planted stands as future seed sources. A moderate improvement in Douglas fir would result. This publication contains generalized site maps, weather records, and much other basic information necessary for the preliminary steps in this work.

Hybridization

Hybridization, usually accomplished by hand pollination, aims beyond mass selection in species improvement. In crop plants it usually starts with the selection of superior individuals or strains having desirable characteristics. The strains are crossed to intensify these characteristics or to obtain in the progeny such desirable characteristics of both parents as rapid growth, good form, hardiness, and resistance to disease. As an example, from forest tree breeding, hybrids produced at the Institute of Forest Genetics (58) exhibit the rapid growth of the Monterey pine and the frost hardiness of the slow-growing knobcone pine.

The first cross of species sometimes results in a growth rate greater than either parent, which is known as "hybrid vigor" (60). To preserve this fast rate of growth, trees are often vegetatively propagated or rooted from cuttings. It is in the perpetuation of strains or the preparation of parent stock that the use of rooting substances may play an important part. This is discussed in the section on artificial regeneration on page 13. Crossing of races or strains which brings about a combination of genes that would never occur under natural conditions may create individuals with entirely new characteristics or qualities of great significance. The crossing of varieties of the same species often requires hand pollination. Yet it is not difficult and among conifers (gymnosperms) usually produces fertile offspring. Crosses between species are more difficult to accomplish and often result in a partial or completely sterile hybrid, but no completely sterile pine hybrid has been reported. This may also be true of Douglas fir or other conifers.

The practicability of using hybrids is explained by Righter (53). At the Institute of Forest Genetics, fertile pine hybrids having the rapid growth rate of one parent and the hardiness of the other are being interplanted with local stock. Because hybrids are more costly than ordinary stock, only enough are used to equal the number of final crop trees (200 per acre). If they prove to be superior, they will assume the dominant position in the stand, and the native stock will be crowded out or taken out as thinnings. The hybrids would thus increase the yield and leave the area in possession of superior parent stock. If the hybrids did not prove superior, the best of the interplanted native stock would naturally take over. While great strides have been made in this field in horticulture and agriculture, the field has only been touched in forestry, and nothing whatever has been done with Douglas fir.

Another field for the use of hybrids, which probably offers the greatest promise, is the furnishing, in the second generation, of entirely new types from which to select the best. Many of our present improved plants started that way.

Polyploidy, or the Increasing of Chromosome Numbers

Chromosomes are tiny, hair-like nuclear bodies that occur in uniform numbers and divide uniformly in the somatic and in the germ cells. If through accident or induced change there is an increase or multiplication of chromosome numbers, termed polyploidy, a partial or complete change in one or more of the important tree characteristics results. Often entirely new forms that are fertile and that breed true to form are produced in this way; occurring naturally, these changes have been called mutations or sports.

This change in chromosome number has been called (19) one of nature's trade secrets that has been given over to science. It can be brought about by sudden temperature change, X-ray, electrical treatment, or the application of drugs such as colchicine and acenaphthene. The new tool of genetics research has produced wonderful changes in flowers and vegetables, but as yet nothing outstanding has been produced with forest trees. Forest geneticists do not hold out great hope for the process.

Polyploidy and hybridization are sometimes used jointly to produce a new fertile form. Chromosomes contributed by parents of hybrids are not always exactly similar and sometimes fail to pair completely, resulting in complete or partial sterility. Treatment of such hybrids to double the chromosome number makes possible perfect pairing in future divisions. A hybrid so treated should be a true-breeding new type. Although it has not yet produced anything outstanding, this process offers most hope to the forest tree breeder. In spite of possibilities offered, very little has been done with Douglas fir in the field of polyploidy beyond observing and counting the number of chromosomes. Douglas fir is reported by some students to have 12 pairs of chromosomes (2) (52), but one reliable authority (56) reports 13 pairs. Most coniferous species examined have 12 pairs.

The Job Ahead

Future work to aid in securing better Douglas fir forests should be divided into two broad fields: Long-time studies of a fundamental nature that require skilled scientists, continuity of effort, and continuously available funds; and short-time work that can be accomplished when funds and personnel are available.

Long-time Studies

(a) First on the list of long-time studies is a thorough test of existing races or strains of Douglas fir. Stands of good growth and form exist over a wide range of climate and soil types—site I stands have been located at elevations up to 3,000 feet.

Good stands should be located in climatic belts and soil types that will cover the range of the major planting areas. Progeny from these stands should then be tested in plantations in representative parts of the commercial planting zone in order to determine what strain is best for a particular locality. This study will have to start with the best known strains but will be supplemented from time to time as new and better strains are found or grow up from stands of natural regeneration. As plantations begin to show results, the results should be used to identify seed-source areas. The establishment of seed-source plantations using selected stock only should follow.

Continuity of financial support, fire protection, and availability of skilled personnel are essential for the conduct of this study. It should be undertaken by some permanent organization.

(b) Another on the list of long-time studies is the problem of species improvement. Douglas fir in its natural state is the most important tree in the region and occupies a prominent place in forestry. There is a wide difference in its rate of growth and the quality of timber produced, and it occurs over a wide range of soil types and climate. The species has several distinct local strains or races, and there are three additional well-recognized species in the genus; some authors name more. Its associates—spruce, hemlock, Port Orford white cedar, and the balsam firs—are all good forest trees and are worthy of consideration. Those qualifications plus the fact that forestry is a major feature in the economy of the Northwest justify a well-rounded program of genetics, including selection, hybridization, and research in polyploidy. No work has been done in the genetic improvement of Douglas fir and its associates to date. In the face of a rapidly expanding reforestation program, this work should not be indefinitely postponed. The existing geographic races of Douglas fir and the other three important species in the genus should be brought in now and placed in plantations, so that material will be on hand to work with when once this work gets under way. To be effective a genetics program must be carried over a considerable period of years, and though urgent, it should not be started unless skilled personnel and funds are continuously available. Periodic short-time studies are worthless except on related phases as noted below. Other longtime studies of lesser importance follow.

(c) Continued studies of the use of substances to aid in root development of coniferous cuttings, aimed toward more simple and less costly processes.

(d) Measure of growth and survival of plantations in which varying percents of inferior or under-size seedlings have been eliminated from the nursery stock.

(e) Study of factors affecting seed production, periodicity of seed crops, and methods of predicting seed crops.

Short-time Studies

(a) First on the list of short-time studies are fundamental studies related to the long-time tests of strains and the genetics program but requiring less time. They are: recording the season of flowering at different elevations; determining the life of pollen and the distance it is carried by the wind; and the identification of local strains of superior quality. Other work that can be done during short periods, when funds and personnel are available, follow.

(b) A public relations job acquainting foresters, nurserymen, and tree planters of any sort with the necessity of securing superior seed and planting stock and the prospects of greater returns therefrom.

(c) From best information available, prepare improved guides for selecting superior strains of seed for a given site, and rules for collecting, labeling, and care of seed.

(d) Perfect and establish some scheme for forest seed certification that will protect the planter.

(e) Locate and certify superior natural strains for seed production, and formulate necessary instructions for the removal of inferior individuals.

(f) Determine if a relation exists between rate of annual growth and such factors as foliage color, cone bearing, comparative thrift, length of leader, or date of bud bursting.

Summary

Forestry is the only great industry that has done little or nothing to improve the wild stock under management; practically nothing has been done to improve Douglas fir. There is now, and will be for years to come, a big job of reforestation in the region. This job starts with seed.

Douglas fir is an excellent tree in the field of forestry and the superior tree for the greater part of this region. But various wild strains of the tree have distinct climatic and soil limitations; seed from such strains should not be used beyond these limits. There is also ample proof that superior-growing strains exist and that it pays to plant the best seed that can be obtained for a given area. Superior strains can multiply net profits or returns and inferior strains are practically sure to result in a net loss. Seed can be collected during heavy crop years and held for years when no seed is produced. It has been demonstrated that Douglas fir can be held in cold storage up to 10 years without serious loss of viability. Superior strains, if climatically suited to an area, can be used to supplement natural regeneration as well as for full artificial regeneration; the methods are outlined. Some sort of system of seed certification is essential. Satisfactory systems are now in use in other countries. Opportunity for stand improvement lies first in selecting the best wild seed available and second, by improvement of the species through genetics. Species improvement comes mostly through mass selection and hybridization. Little or no work has as yet been done in most of these fields with Douglas fir even though it is one of the nation's outstanding timber trees.

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Fig. 10—A young-growth Douglas fir stand approaching the seed-bearing age. Individual trees in a stand vary and good form is as important as good growth in seed tree selection. Trees 1, 2, 3, 4, and 5 are poor form and excessively limby; their offspring would be likely to have similar characteristics. Trees A, B, C, and D are better form, have cleaner boles and are making equally good growth. This type of tree should be selected in seed collection.

(Photo, courtesy West Coast Lumbermen's Association)