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UNITED STATES DEPARTMENT OF AGRICULTURE

DEPARTMENT BULLETIN No. 1200

Washington, D. C. ▼ April, 1924

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THE NATURAL REGENERATION OF DOUGLAS FIR IN THE PACIFIC NORTHWEST

By

JULIUS V. HOFMANN, Silviculturist, Wind River Forest Experiment Station, Forest Service

CONTENTS

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NATURAL REGENERATION OF DOUGLAS FIR IN THE PACIFIC NORTHWEST

By JULIUS V. HOFMANN, *Silviculturist, Wind River Forest Experiment Station, Forest Service.*

CONTENTS.

INTRODUCTION.

The Douglas-fir[1] forests of Oregon and Washington are among the most valuable in the United States, but because the means by which they can be regenerated have not been understood or followed, about half the 3,500,000 acres[2] cut over in Oregon and Washington are nonproductive. To this denuded land are being added from 80,000 to 100,000 acres each year, an amount that will tend to increase as other timber regions become exhausted and the Pacific Northwest is called on for more and more of our national lumber supply. So productive are Douglas-fir forests that well-stocked stands grow at an average rate of about 600 board feet to the acre annually up to an age of about 200 years. The nonproductive cut-over Douglas-fir lands of Oregon and Washington could, at this rate, be now producing over a billion board feet a year—about one-seventh of the total present yearly cut of this region. To trace the laws governing the establishment and growth of Douglas-fir for-

[1] Douglas fir (*Pseudotsuga taxifolia*) (Poir. Britt.) is known by a number of common names, such as Washington fir, red fir, yellow fir, fir, Douglas spruce, spruce, Oregon pine, red pine, Puget Sound pine, or British Columbia pine.

[2] Report on Senate Resolution 311, Timber Depletion, Lumber Prices, Lumber Exports, and Concentration of Timber Ownership. U. S. Department of Agriculture, Forest Service, June 1, 1920.

NOTE.—Grateful acknowledgment is made of the valuable assistance of C. J. Kraebel, forest examiner, and H. V. Brown, forest ranger.

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ests and the methods by which new stands may be obtained is the purpose of this publication.

Douglas fir is so intimately related to other species in establishment and growth that it is necessary in a discussion of this kind to consider its chief associates, such as western red cedar (*Thuja plicata* Don.), western hemlock (*Tsuga heterophylla* (Raf.) Sarg.).

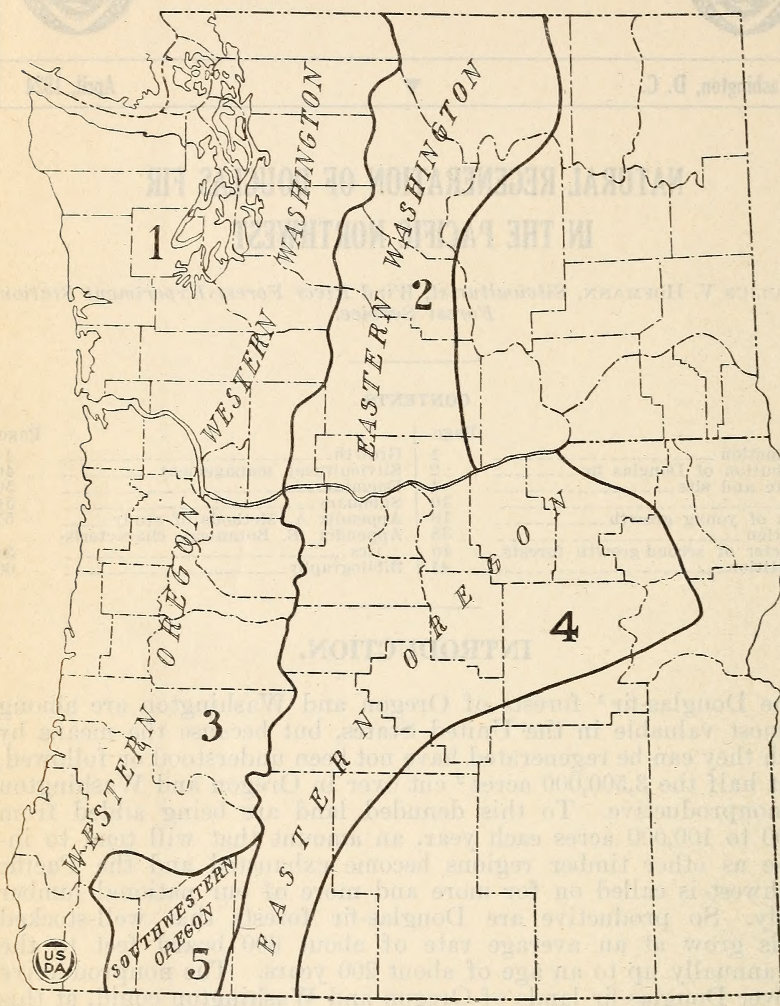

FIG. 1.—Regional distribution of Douglas fir in Oregon and Washington.

noble fir (*Abies nobilis* Lindl.), silver fir (*Abies amabilis* Forb.), and others.[3]

DISTRIBUTION OF DOUGLAS FIR.

The local distribution of Douglas fir in Oregon and Washington is definitely related with the climatic conditions prevailing in the

[3] For methods of study used in this investigation, see Appendix A.

different parts of the region. These relations are brought out by Figure 1 and Table 1. The limits of the range of Douglas fir are shown in Figure 2.

The climatic units into which the Douglas fir region of Oregon and Washington has been divided in Table 1 are based on weather records taken at the regular Weather Bureau stations. Although the weather records often are not taken at points typical of the forest regions, the averages of the records taken at all stations of each region are reliable indices of the relative differences between its climatic characteristics and those of other regions similarly determined.

TABLE 1.—*Temperature and precipitation in the Douglas-fir region of Oregon and Washington based on records through periods of 5 to 64 years, with an average of about 16 years.*[1]

	Mean annual temperature.	Highest temperature.	Lowest temperature.	Mean temperature growing season.	Mean annual precipitation.	Maximum annual rainfall.
	°F.	*°F.*	*°F.*	*°F.*	*Inches.*	*Inches.*
Washington:						
West of Cascades	50.2	105	−6	56.5	55.56	[2] 151.56
East of Cascades	47.7	108	−30	61.3	14.75	[3] 35.77
Oregon:						
West of Cascades	51.1	108	−16	57.4	59.51	[4] 167.29
Southwestern section	52.7	110	−4	63.1	31.44	[5] 62.66
East of Cascades	56.5	119	−27	63.6	14.55	[6] 43.65

	Minimum rainfall.	Precipitation during growing season.	Annual number of days in the growing season.	Latest date of killing frost in spring.	Earliest date of killing frost in autumn.
	Inches.	*Inches.*			
Washington:					
West of Cascades	[7] 15.00	18.66	[8] 199	Apr. 6	Oct. 30
East of Cascades	[9] 3.71	2.69	135	May 25	Sept 30
Oregon:					
West of Cascades	[10] 15.53	17.29	197	Apr. 17	Oct. 31
Southwestern section	[11] 11.99	4.90	164	May 7	Oct. 13
East of Cascades	[12] 4.60	3.21	142	May 18	Oct. 2

[1] United States Department of Agriculture, Weather Bureau records. For location of regions see figure 1.
[2] Clearwater, Jefferson County, 1899.
[3] Lyle, Klickitat County, 1894.
[4] Glenora, Tillamook County, 1896.
[5] West Fork, Douglas County, 1896.
[6] The Dalles, Wasco County, 1858.
[7] Port Townsend, Jefferson County, 1889.
[8] The length of the growing season does not coincide with the average dates of earliest and latest frosts due to the variation of the length of the periods through which records were taken.
[9] Ellensburg, Kittitas County, 1898.
[10] Roseburg, Douglas County, 1913.
[11] Ashland, Jackson County, 1905.
[12] Umatilla, Umatilla County, 1898.

In western Oregon and Washington Douglas fir is not exacting in its choice of site, except as it is influenced by altitude and latitude. This is chiefly because there is enough precipitation, especially during the long favorable growing season, to insure the establishment of the seedling and to enable it to compete successfully with other species of trees and with shrubs. The longer growing season on the west side not only enables the Douglas fir to continue growth through a longer period, but it also insures better maturity, so that there is less frost injury than on the east side. Its best development is below the altitude of 3,000 feet, although in Oregon it produces good timber trees up to about 4,300 feet. Its growth is always checked and sometimes inhibited by exposure to severe winds. For this reason it is not found near the open sea in exposed localities, although it occurs near by in sheltered inlets where protection is afforded.

In eastern Oregon and Washington the Douglas fir either forms a mixed stand with species which usually occur on drier sites, such as western yellow pine (*Pinus ponderosa* Laws.) and lodgepole pine (*P. contorta* Loud.), or it is found on moist slopes in mixture with species that require more moisture, such as western larch (*Larix occidentalis* Nutt.), white fir (*Abies concolor* Lindl. & Gord.) and western hemlock. In either situation it produces inferior trees as compared with those produced in the western sections. This condition is readily explained by the limited precipitation during the growing season, the shorter growing season, and other climatic factors.

In southwestern Oregon[4] the Douglas-fir forest meets the western yellow pine, knobcone pine (*Pinus attenuata* Lemm.), and other species, and forms what may be called the border type, which is typical of the region. Douglas fir covers the north slopes, and western yellow pine the south slopes, and many variations of these types also occur.

CLIMATE AND SITE.

Before proceeding to the main discussion of natural regeneration, it is desirable to consider briefly some of the climatic and site requirements of Douglas fir and its habits of seeding, because it is in these peculiarities that the solution of the problem lies. These subjects are discussed in the next two chapters.

LIGHT.

The western white pine (*Pinus monticola* Dougl.) is the only tree of the Pacific Northwest that requires more light than Douglas fir. The Douglas fir will grow in about one-fourth of the full light in adjoining open areas, although under these conditions its development is retarded, and the more shade-enduring species, such as western red cedar, western hemlock, and Sitka spruce (*Picea sitchensis* (Bong.) Traut & Mayer) have the advantage.

The inability of Douglas fir to thrive in diffused light makes it incapable of forming an understory. This characteristic is a disadvantage to the tree in retaining its position in the forest, for the more shade-enduring species crowd out the Douglas fir and often completely replace it in the stand; but it is an advantage from a commercial standpoint, for this inability to withstand shade results in early pruning of the branches, so that a comparatively clear, straight bole is produced early in the development of the tree. On favorable sites, where the stands are dense, clear boles begin to form at 30 to 40 years of age, and at 40 to 50 years of age clear boles as high as 40 feet are often found. These characteristics illustrate the importance of a complete stand of young growth and the advantages of an even-aged stand. The relatively greater height growth of

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[4] This region, bounded on the west by the towns of Riddle, West Fork, Galice, and Mountain Ranch, on the north by the Umpqua River, and on the east by the Cascade Mountains, is referred to hereafter as southwestern Oregon.

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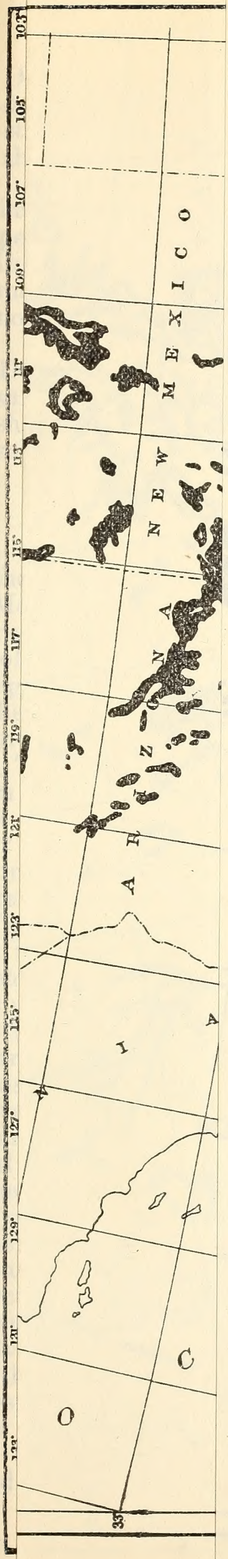

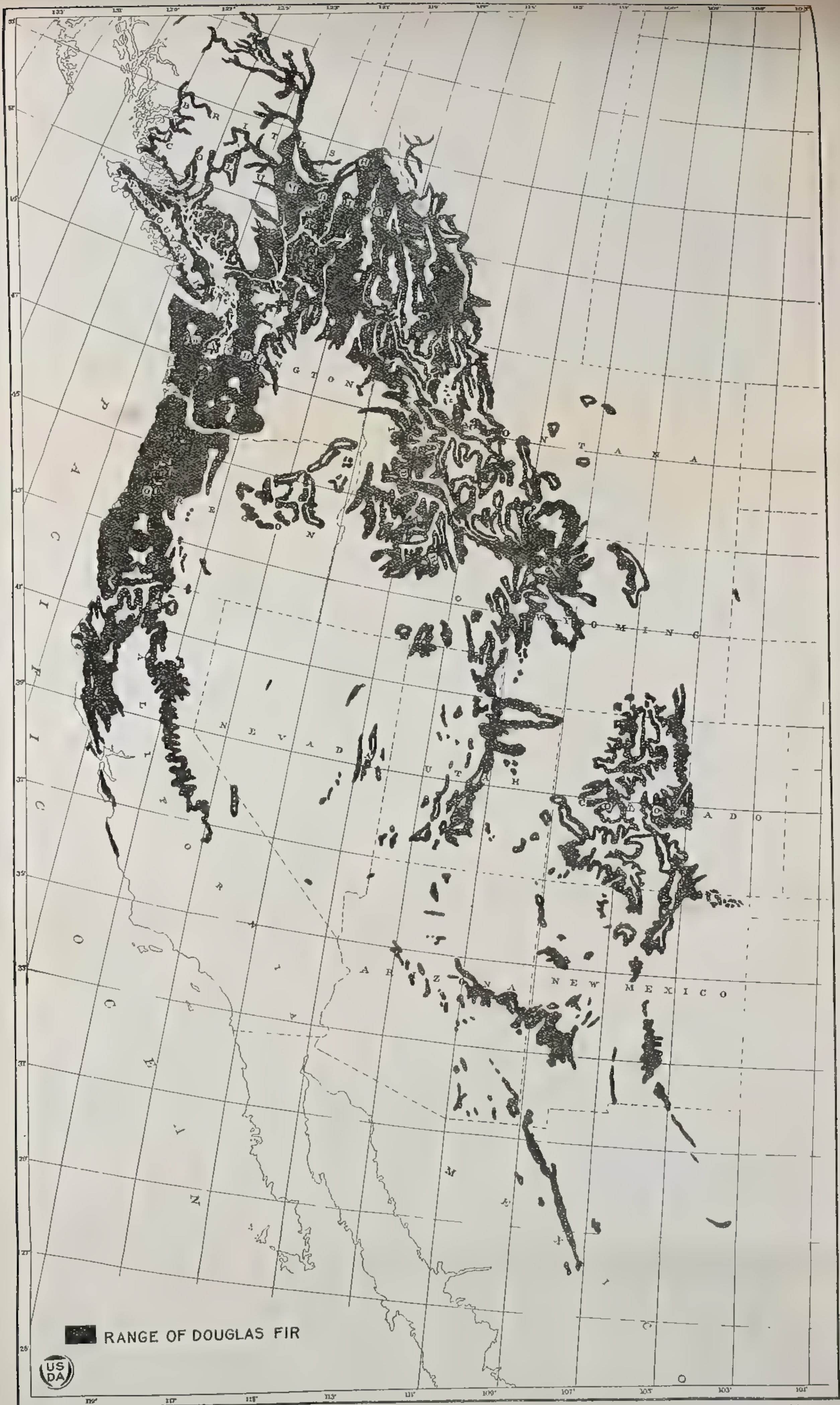

FIG. 2.—Distribution of Douglas fir.

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Douglas fir during its early years helps to maintain it. Because it demands an abundance of overhead light, it produces the tallest and straightest stems in dense pure stands or in mixture with the more shade-enduring species.

On the sites of poorer quality, especially in open stands, the lateral branches are persistent and form hard, dense wood. These branches persist for 20 or 30 years after all foliage has died, and are embedded in a large section of the trunk. In localities where the growth is more rapid the lateral branches contain much softer wood and are not so persistent after the foliage has died.

On good sites the favorable soil and abundant moisture enable Douglas-fir seedlings to endure more shade than on poorer sites. The same conditions also favor increased survival and growth of the shade-enduring western red cedar and western hemlock, with the result that they often crowd out the Douglas fir.

TEMPERATURE.

Douglas fir is apparently adapted to severe climatic conditions in the Rocky Mountain region and on the east slopes of the Cascade Mountains of Oregon and Washington. However, the fast-growing Pacific-slope form of the species does not bear exposure to severe cold. In winter the cold, dry east winds sometimes kill the trees outright and often kill the growing tips, especially on the east side of the trees. Such conditions are particularly injurious to young trees and either retard growth or kill the seedlings.

Throughout the range of Douglas fir the seedlings are often killed on hot, exposed slopes through injury by heat to the cambium ring at the surface of the ground. It has been found that a temperature of 144° F. at the surface of the soil kills the cambium and causes girdling of the seedlings. This injury often affects seedlings or transplants in the nursery and has been described as "stem girdle." The cambium of older Douglas firs separates from the sapwood when it is heated above 160° F., and occasionally a scar results. If the temperature is raised to 200° F., the cambium becomes discolored and is permanently injured.

The length of the growing season in the Douglas fir region is variable, and the seedlings have apparently not become adapted to this variability. Often late spring or early fall frosts cause extensive injury to young growth. If frosts occur after growth has started or before the buds mature, the buds—particularly the terminal buds—suffer, height growth is checked or completely stopped for one or more seasons, and the bushy seedlings, so common up to 4 or 5 years old, are formed. If the terminal buds are killed by frost, the lateral or adventitious buds develop, and it may be three or more years before a leading shoot is formed. The actual killing of young growth by frost is not common, but the death of seedlings as the result of heaving by frost is often extensive. The principal disadvantage resulting to the tree, from its inability to withstand frost, is the loss of its place among its competitors. Western hemlock and western red cedar are often found uninjured by frost that has killed the immature buds of Douglas fir. When in mixture with Douglas fir these species take advantage of the retardation of Douglas fir and overtop it, thus eliminating it from the stands.

MOISTURE.

Although young Douglas fir is found distributed on all sites throughout the region, its successful establishment and growth are largely controlled by moisture. The poor growth along the Columbia River gorge, as compared with the adjoining side valleys, may be attributed to the drying east winds that sweep down the gorge. These winds cause excessive transpiration, which makes the buds mature early and consequently shortens the growing season.

Site studies have been made in different localities, and the soil moisture correlated with the establishment and survival of Douglas-fir seedlings. The ability to extend its root system 6 or 8 inches deep during the early part of its first growing season is an important factor in perpetuating Douglas fir. When it is in competition with such other species as western red cedar and western hemlock, which produce shallow-rooted seedlings, the Douglas fir often is able to survive where the other species fail.

Records of soil moisture taken in 1919 on the flat river bottoms and south slopes in the Cispus burn, near the Tower Rock Ranger Station north of Mount Adams, demonstrated the ability of the Douglas fir to resist the adverse conditions of severe sites. On the south slope the moisture in the surface soil reached a minimum of 0.18 per cent in July and did not go above 0.85 per cent in August. At a depth of 6 inches the south slope soil contained 6.55 per cent of moisture in July and 5.50 per cent in August. The wilting coefficient of 2-year-old Douglas fir seedlings was found to be 1.25 per cent for this soil.[5] These data show conclusively that seedlings could not live in the surface layer of the soil, because the available moisture was below their requirement. At a depth of 6 inches, however, there was sufficient moisture for growth throughout the season. In the flat river valley, where the soil is a silt loam, the surface soil contained 0.19 per cent of moisture in July and 0.09 per cent in August. At a depth of 6 inches the soil contained 11.45 per cent of moisture in July and 9.32 per cent in August. Obviously, then, seedlings that have root systems which penetrate to a 6-inch depth before July of their first season may become established in this region.

These extremes of soil moisture are readily explained by the records of soil temperature and evaporation. The surface soil on the south slope reached a maximum temperature of 128° F. in July and 135° F. in August. From July 15 to October 1 evaporation records with the Forest Service evaporimeter showed an evaporation of 1,070 cubic centimeters on the south slope as compared with 690 cubic centimeters on the flat; that is, more than one and one-half times as much on the slope as on the flat. With such severe conditions of temperature and moisture only those Douglas-fir seedlings that are protected by shrubs or annual plants survive the first one or two dry seasons and become established.

After a forest canopy is formed and duff accumulates on the ground the site becomes more favorable; western red cedar and western hemlock are then able, gradually, to gain a foothold in the

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[5] Hofmann, J. V. The Establishment of a Douglas Fir Forest. Ecology, vol. 1, No. 1, January, 1920.

Douglas-fir forests, and so prevent Douglas fir from being the dominant tree for more than the first generation, except in those localities which western red cedar or western hemlock do not reach by migration until two or more generations of Douglas fir have occupied the ground.

During the summer of 1913 meteorological readings were taken on the north slope, south slope, and flat of Warrens Gap in the Wind River Valley in southern Washington.[6] Some of the important points shown by these readings are the maximum temperature of the surface soil, soil moisture, and evaporation. The extremes of all the factors mentioned occurred in July and August, which is the critical period for plants in this region. With a surface-soil temperature of 129.4° F. occurring on the south slope, while the north-slope maximum was 82.4° F., and with a surface-soil moisture of only 1 per cent on the south slope as compared with 6.5 per cent on the north slope, there is little need to conjecture about the failure of small, shallow-rooted seedlings on the south slope.

The comparatively short period of drought in this region, however, ordinarily enables the Douglas-fir seedlings to become established. Although the surface soil dries out to the point where seedlings can not survive, the water content of the soil at a depth of 6 inches usually remains above their minimum need. The soil moisture remained at 11.2 per cent on the south slope and 17.5 per cent on the north slope at a depth of 6 inches. This amount of water produces favorable conditions for growth. Although the water content of the soil is above the minimum requirement of the plant, generally the drier sites are exposed to higher temperatures and greater transpiration. The striking effect of evaporation on these sites is shown by the evaporation from open-water surfaces exposed only to vertical radiation, as, for the most part, are masses of vegetation. On the south slope 15.1 inches of water evaporated from an open water tank during the month of August, while only 1.8 inches evaporated on the north slope and 6 inches on the flat. The effect of protection from the sun's rays on plants is shown by the survival of seedlings under the protection of shrubs on these severe sites and by their failure in the open, even where the moisture content of the soil is about the same. The greater demand for moisture by seedlings in the open because of greater transpiration can not be supplied when the moisture content of the soil approaches the minimum requirement.

A vegetative cover of either pea vine or brush has a noticeable effect on the moisture content of the soil. To determine this effect on a south exposure, an area was selected where the pea vine was very dense. One square rod was denuded of all vegetation, and the area beside the denuded plot was left intact. Readings of air temperature at the height of the crowns of seedlings, and of soil temperature at the surface and at depths of 6 and 12 inches, were taken each week on each area. The results are given in Tables 2 and 3.

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[6] Hofmann, J. V. The Importance of Seed Characteristics in the Natural Reproduction of Coniferous Forests. Studies in the Biological Sciences, No. 2, University of Minnesota. 1918.

TABLE 2.—*Effect of vegetative cover on air and soil temperature.*

	Average maxima—Degrees Fahrenheit.					
	May.	June.	July.	August.	September.	October.
Air temperature:[1]						
Natural cover	60.8	59.2	70.7	86.6	72.0	55.7
Denuded	72.2	64.4	84.7	102.8	76.2	60.0
Soil temperature:						
Natural cover, surface	55.6	56.0	62.7	73.4	63.5	56.2
Natural cover, 6 inches deep	52.2	55.2	60.5	68.4	61.0	54.5
Natural cover, 12 inches deep	50.9	55.0	60.0	66.4	60.6	54.5
Denuded, surface	74.5	67.5	92.5	124.2	89.2	64.5
Denuded, 6 inches deep	57.8	62.0	68.0	78.7	67.0	54.2
Denuded, 12 inches deep	56.3	61.5	67.0	74.4	66.2	56.2

[1] Air temperature taken at the crown of 1-year-old seedlings.

Table 3 shows clearly the effect of evaporation from surface soil. In August the moisture in the denuded soil was 1 per cent, as compared with 10.5 per cent under the natural cover. The percentage of soil moisture at the 6-inch and 12-inch depths, however, was greater during the dry season on the denuded area than on the area having the natural cover of vegetation, because, where this cover was present, the moisture from the soil was absorbed by the roots of the plants.

TABLE 3.—*Effect of vegetative cover on soil-moisture content.*

	Average percentages of soil moisture.					
	May.	June.	July.	August.	September.	October.
Natural cover:						
Surface	33.3	32.4	23.1	10.5	33.4	36.5
6 inches deep	21.3	26.7	20.0	12.9	29.5	26.5
12 inches deep	23.9	20.5	18.6	15.4	28.4	27.7
Denuded:						
Surface	11.0	10.2	4.1	1.0	12.7	18.4
6 inches deep	26.7	24.1	22.5	17.5	24.2	29.0
12 inches deep	23.2	25.7	21.1	19.8	27.2	29.2

The extreme maximum temperature of the surface soil of 124.2° F. in the denuded area, as compared with 73.4° F. at the same time under the natural cover, shows clearly to what rigorous conditions the seedlings are exposed when growing in the open on these severe slopes. The 12.9 per cent of soil moisture at the 6-inch depth in the natural cover, and the 17.5 per cent at the 6-inch depth in the denuded area, is evidence that seedlings with root systems 6 inches and deeper have moisture available even during extreme droughts. The deciding factor here, however, is the amount of drying resulting from the exposure of the plant. A plant in the open is under a much more severe test than a plant under natural cover, for a plant exposed to the sun becomes considerably warmer than the surrounding air, whereas shaded plants become colder than the air.

Even if the soil moisture is equal in two localities, the soil texture may have a decided influence on the availability of the moisture to the plants, as expressed by a marked difference in the wilting coefficients. This difference would not influence the types if the soil moisture were the same at all depths. But the fact that the surface soil often dries out, while the soil at a depth of 6 inches remains moist on protected slopes and dries on exposed slopes, changes the type and gives a decided advantage to the seedling with a deep root formed early in its development. In its early root growth the western yellow pine has the advantage over Douglas fir, western hemlock, and western red cedar, and it is largely on this account that the yellow pine forms the dry-slope type in the border zone of the Douglas-fir forest region.

For the same reason Douglas fir is able to establish itself on the drier slopes of the Cascades, where the western red cedar and western hemlock fail. A south slope covered with Douglas fir and a north slope covered with western hemlock, western red cedar, and other species does not prove that each of these species is in its most favorable situation, but that these are instances of successful competition and establishment. Where two types met on a ridge it was found that the south slope was seeded by the species of the north slope, and the seedlings of western hemlock and western red cedar were germinating along with those of the Douglas fir and western yellow pine in the spring. When the area was examined in the fall only seedlings of the western yellow pine and Douglas fir were left, because the small seedlings of the other species were unable to live through the dry period of the summer on account of their shorter roots and conseqent inability to reach the moist layer of soil below the dry surface. These conditions are repeated year after year, and still the type remains the same.[7] It is very noticeable that wherever a ravine or spring keeps the south slope moist the north-slope species are found. Evaporation, then, is one of the chief factors in the establishment of the seedlings, for, while the different slopes often get about the same amount of precipitation, there is such a marked difference in evaporation that the exposed slopes dry out while the north and protected slopes remain moist.

SOIL.

The loose volcanic-ash soil found in the Cispus region northwest of Mount Adams heats during a forest fire or when exposed to the sun's rays. In this type of soil fire causes complete destruction of all vegetable matter and the seed stored in the forest floor is destroyed. The importance of seed stored in the forest floor in natural reforestation is discussed later. The hot, dry soil in these burned areas prevents establishment of seedlings after the fire. On the other hand, the heavy loam soil of the Willamette Valley and of other similar regions protects the forest floor from the heat of fires, and the greater moisture-holding capacity of this type of soil aids reforestation.

Douglas fir grows best on sandy loam and reaches its greatest size on moist, porous, well-drained soil. It is absent from the wet bottomland and marshy places and sphagnum bogs, on which Sitka spruce and lodgepole pine grow fairly well. It seldom occurs on light, dry, sandy soil or on heavy clay soil, and where it does occur on these soils it usually forms a light stand of poorly developed trees.

[7] Hofmann, J. V. Seed Vitality as a Factor in Determining Forest Types. The Ames Forester, Iowa State College, 1917.

Soil may be largely responsible for limiting the distribution of a species, especially in local areas. Thus on the areas of serpentine in the Siskiyou Mountains of southwestern Oregon, knobcone pine produces a better growth during its seedling and pole stages than Douglas fir and takes possession of such shallow soil areas. Although the knobcone pine is only a scrub tree, the soil enables it to compete successfully with its associated timber trees, including the Douglas fir.

The loose soil in the Coast and Cascade Mountain regions of Oregon and Washington affords good drainage, prevents erosion, and, with abundant rainfall, is very favorable to the growth of Douglas fir.

SEED.

The proposed methods of natural restocking of Douglas fir are in large part based on the characteristics of the seed and the storage of seed in the forest floor. In order to assure a stand of young growth after forest fires or logging, good crops of seed must be produced, and the seed must be distributed and be able to retain its vitality until it has an opportunity to germinate. A study of the seed has established important facts concerning its production, distribution, germination, and viability—facts that must be clearly understood as the first step in solving the problem of natural regeneration of Douglas fir.

SEED PRODUCTION.

In the Douglas fir good seed years occur at irregular intervals, usually two or three years apart. Sometimes a fair crop of seed follows after a very heavy crop, and at other times practically no seed is produced in this region following a heavy seed year. Seed production is unquestionably influenced by the condition of the weather during the period of pollination. During seasons in which rains began at about the time the staminate flowers opened, and continuous wet weather prevailed throughout the season of pollination, it was noted that the staminate flowers drooped, the pollen adhered to the stamens, and there was apparently very little distribution of the pollen. Even on trees that produced a good crop of pistillate flowers there were practically no cones. As the pistillate flowers are at the ends of the branches and the staminate flowers further down, there is very little pollination on the same branch, and the distribution of pollen to other branches is very limited on account of its sticky condition. The wide variation of climatic conditions in mountainous regions causes a corresponding variation in the time of flowering. Although the staminate flowers on the same tree may mature before the pistillate, the trees at a higher elevation, in the same vicinity, may produce pollen at the proper time to fertilize the pistillate flowers of the trees in the valley. This cross-pollination tends to eliminate individuality among trees in the same locality, in so far as fertilization is concerned, although there are other factors affecting the development of the seed, such as soil and age of tree.

The distribution by wind of the pollen of Douglas fir may cause cross-pollination for long distances during favorable periods. Pollen grains of forest trees may be carried as far as 80 or 90 miles by wind.[8] The method of pollination is an important factor in the seed production of trees that are left after logging or after a forest fire. Diseased trees are known to produce only about three-fifths as much good seed as sound trees.[9] The smaller amount of good seed produced by diseased trees may be due to the infertility of the pollen. If diseased trees only were left on an area, the quantity of good seed produced would be small, and that might be a serious factor in seed production. However, if some diseased trees were left on a cutting area, and if a stand of Douglas fir remained in the surrounding territory, there would always be a chance of fertilization with pollen produced by sound trees. In that event the seed production would not be seriously handicapped.

The average mature Douglas fir tree produces about 40,000 seeds per crop. There is a wide variation in seed production due to the age, size, and health of the tree, density of stand, soil, latitude, and altitude. Each of these factors influences seed production, although the direct effect of each individual factor can not be definitely stated. Trees 100 to 200 years old bear most prolifically. It was found that the average 15-year-old tree produced 4,000 seeds, the average 100 to 200 year old tree produced 40,000 seeds, and the average 600-year-old tree produced 7,000 seeds. At elevations of 300 to 600 feet above sea level the average tree produced about 34,000 seeds per crop as compared with 4,000 seeds for the average tree at 3,000 to 4,000 feet above sea level. The effect of latitude is noticeable even within the limits of Oregon and Washington. The average tree in central Oregon produced 35,000 seeds per tree, but a comparable average tree in northern Washington produced only 7,000 seeds. This, apparently, is a wide variation and may not be consistently maintained during each seed crop, but the figures indicate that latitude has a marked influence on seed production. The effect of the health of the tree is very noticeable. Diseased trees that were severely affected produced 7,700 seeds per tree, but sound trees of the same age class and same locality produced 14,200 seeds. In the check taken there was little effect in quantity production of seed that could be traced directly to soil conditions. The quality of the seed was the noticeable varying factor. Trees on poor soil produced only two-thirds as many good seeds as trees on good soil.

Another factor which must not be overlooked in seed production in Oregon and Washington is the damage done by the insect *Megastigmus spermotrophus* Wachtl. This insect is always present and attacks some of the seed, but in a light seed year concentrates its attacks and becomes most destructive. For this reason a sparse seed crop in Douglas fir is usually equivalent to a failure.

A careful examination of the cones before the seed matures during July and August will usually reveal immature stages of the seed-infesting insects. If cones of the past season are examined during the winter and spring, they will indicate whether or not the area is infested by these insects.

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[8] Hesselman, Henrik, Iakttagelser över Skogsträdspollens Spridningsförmaga (Dissemination of Pollen from Forest Trees). Meddel. Statens Skogsförsöksanst, 16: 27–60. 1919.

[9] Willis, C. P., and Hofmann, J. V. A Study of Douglas Fir Seed. Proceedings of the Society of American Foresters, Vol. X, No. 2, pp. 141–164. 1915.

The amount of seed destroyed by rodents also enters into the final result of the seed crop. Mice, chipmunks, and squirrels are very active in collecting and storing seeds and cones, their chief source of food, especially during the period of ripening. It has been noted that a white-footed mouse will eat 300 and a chipmunk 600 Douglas-fir seeds a day when in captivity.[10] In regions where rodents are abundant, light crops of seeds are entirely consumed, as are also the seeds produced by scattered seed trees.

The average Douglas-fir tree produces about 2½ bushels of cones per tree, with an average of 1,000 cones per bushel. Sometimes the number of cones produced is the direct cause of the variation in the amount of seed produced. However, diseased trees on poor soil produce almost as many cones as do sound trees and trees on good soil, and the variation in effective seed production is due entirely to the quality of seed produced. Other factors that effect the production of cones also effect the production of seed in direct proportion. The yield of cones per tree is greatest with medium-aged, good-sized trees that grow in open stands in warm localities.

SEED DISTRIBUTION.

The chief agents of distribution, or the determining factors in the migration or extension of the range of the species, are wind, animals, man, gravity, and sometimes in mountainous regions landslides and snowslides.

Wind had always been considered the prime agent in the migration of conifers in the Pacific Northwest until investigations showed that its influence is not so far-reaching as was formerly believed. An instance was noted of seed distribution from Douglas-fir trees about 125 feet tall at a time when the wind was blowing 15 to 20 miles an hour. It appeared that at least 90 per cent of the seeds fell within 1 chain (66 feet) of the parent tree, and not over 5 per cent were carried more than 2 chains. Occasionally seeds were carried great distances. Several seeds that were carried by the wind from 6 to 10 chains were gathered and found to be only empty shells, incapable of germination. This no doubt accounted for their separation from the other heavier seeds, which because of their weight continued their spiral course downward. Wind is a definite and persistent agent of distribution and occasionally carries seeds for long distances, but it usually is effective for distances of only 3 to 5 chains from the parent tree. No dense stands of young growth, resulting from wind distribution, have been found at greater distances than these from seed trees.

Rodents are among the important factors affecting the distribution of Douglas-fir seed, although in an indirect way. Rodents gather seed and store it in the forest floor for food, but do not carry it far from the seed trees. When they return, perhaps after a period of rain or snow, they fail to find a good deal of the seed. Tests have shown that mice detect seed by scent, and that they are better able to find seed in mineral soil than in duff, especially when the duff is more than three-fourths of an inch deep. The seed buried by rodents furnishes the supply of stored seed needed for

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[10] Willis, C. P. The Control of Rodents in Field Sowing. Proceedings of the Society of American Foresters, Vol. IX, No. 3. 1914.

forest renewal when the forest is removed by fire or cutting. (Pl. I, fig. 1.)

The unintentional influence of man as a distributing agent on the large burns or barren areas is negligible.

Gravity assists distribution in mountainous or hilly regions.

GERMINATION AND SEEDLING DEVELOPMENT.

The factors necessary for germination are aeration, moisture, and favorable temperature.

Aeration is essential for plant growth, and the lack of it causes poor growth or death in growing plants and dormancy in seeds. Even though conditions may be favorable for the germination of seeds, a lack of oxygen resulting from inadequate aeration will keep them dormant. The seed that is buried out of reach of the air or is in moist duff where the oxygen supply is small may remain dormant for long periods. Moisture is necessary to start germination, but too much moisture may cause the death of the young sprout by the exclusion of oxygen.

Although the seed may have sufficient moisture and oxygen for germination, it will remain dormant if it is kept cool. This is often the chief factor in keeping the seed dormant in the forest floor. When the forest is removed, the temperature of the litter and soil is raised and the seed springs to life. These same factors, with the addition of light, cause the seedlings to develop. However, a wide variation of any one of these factors on different sites does not mean that the widely varying factor is the one which determines the type, because other factors, varying less but approaching nearer to the limit of favorable conditions, may have a great influence on the establishment of the seedling or on the germination of the seed. All the factors must be taken into consideration, and particularly the limits of each under which the seedlings will grow.

The early development of the seedling is dependent on the food stored in the endosperm of the seed. This was demonstrated by sowing seeds of western yellow pine, Douglas fir, western hemlock, and western red cedar in sand, in soil to which nutrient solutions had been added, in potting soil made up of leaf mold and sand, and by germinating the seeds in distilled water. The following nutrient solution was used: To each liter of water were added 1 gram calcium nitrate, 0.25 gram potassium chloride, 0.25 gram magnesium sulphate, and 0.25 gram acid potassium phosphate. The soil was moistened with this solution and watered with it whenever necessary. The seeds germinated equally well under all of the conditions, but differences were noticeable very soon after germination. Seedlings that germinated in the sand came above the ground and appeared to be as good as those grown in the potting soil or in the nutrient solution until the seed coats were shed; then they began to fail, and apparently were unable to get any nourishment or, at least, not a sufficient amount to make growth. After the cotyledon stage these seedlings did not appear healthy; they either developed their resting buds or died. Those in the potting soil and in the nutrient solutions made a good growth and did not develop buds until they had passed through the regular growing period. Those grown in distilled water developed until the food in the seed was exhausted, and then they died.

Seeds in the forest floor are often covered with deep layers of litter and duff, and when the forest is removed the conditions may be favorable for the germination of the seeds. If, however, the seeds are buried too deeply the food in the seed is not sufficient to enable the seedling to grow to the surface. The effect of depth of cover, and the superiority of the seedling which springs from a large seed, are shown in Table 4.

TABLE 4.—*Effect of depth of cover on germination.*

Species.	Depth of cover.	Germinated.	Appeared above ground.	Species.	Depth of cover.	Germinated.	Appeared above ground.
	Inches.	*Per ct.*	*Per ct.*		*Inches.*	*Per ct.*	*Per ct.*
Western yellow pine	1	82	82	Western hemlock	0.25	96	96
	2	83	74		.5	92	76
	3	71	42		.75	86	50
	4	36	0		1.0	64	5
Douglas fir	.5	93	93		1.25	42	0
	1	87	85	Western red cedar	.12	78	78
	1.5	72	64		.25	64	52
	2	67	50		.5	42	24
	3	42	3		.75	25	4
	4	17	0		1.0	26	0
					1.5	19	0

Table 4 shows that seedlings will come up through a depth of soil in direct proportion to the size of the seed, and the development of the seedlings proves that they will grow to a size directly proportional to the size of the seed without any nourishment other than that stored in the endosperm of the seed. The fact that the seeds germinated even at the depth shown in this table and produced roots sometimes 4 to 5 inches long, as did the western yellow pine, shows that the seedling is nourished by food stored in the seed until it can produce chlorophyll bodies and manufacture its own food. If it can not reach the surface before the supply of nourishment in the seed is exhausted, it must die. If the seedling is able to get above the ground, even as a final effort, the cotyledons open at once and turn green, and the seedling gets a new supply of food.

The loss of many of the seedlings germinating in the shade is caused by disease and is due only indirectly to shading, because the shade and moisture favor the development of the damping-off fungi. This may account for more of the seedlings being found in the open, but it does not necessarily mean that the species involved will not develop under more shade. The amount of shading that seedlings will endure largely determines the understory and, consequently, the succession of species. Douglas-fir seedlings will not survive in as dense shade as will the seedlings of western hemlock and western red cedar. For this reason the latter species eventually gain possession of an area that remains undisturbed.

SEED VIABILITY.

Viability of seed is one of the most important factors in the immediate reproduction of the forest as well as in the retention of a forest type. When a forest is destroyed by fire, wind, cutting, or other agencies, the immediate replacement of that forest depends upon the available supply of seed.[11] The species that is able to restock the area first may hold it through several generations or permanently, but to do so it must have a supply of seed at hand. There is no more immediate supply of seed than that stored in the forest floor, and the species that has a supply of stored seed takes possession of the area. In order to have a supply of stored seed, seed production and distribution are essential, but the viability of the seed is even more important. Seed may be stored, but if it does not retain its vitality it is of no avail to the species in replacing a forest. The condition found in the forest floor is shown in Plate I, Figure 2.

RESISTANCE OF DOUGLAS FIR SEED TO HEAT.

To find what temperature would kill Douglas-fir seed, lots of 200 seeds each were subjected for 10 hours to dry oven heat at temperatures from 100° to 300° F. Another series of tests, with temperatures varying from 100° to 240° F., was made in an oven in which the air was kept as nearly saturated as possible with water vapor.

Table 5 shows the germination from seed which was subjected to these heating tests.

TABLE 5.—*Effect of heat on germination of Douglas-fir seed.*

	Check not heated.	Degrees Fahrenheit of heat applied for 10 hours.						
		100	140	160	180	200	220	240
Percentage of germination:								
Dry heat	55	64	62	61.5	73	0.5	0	0
Moist heat	55	65	60	24	0	0	0	0

Douglas-fir seed will withstand a dry heat up to 200° F. and a moist heat up to 160° F. for long periods. The effect of heat upon the seeds was studied with the microscope. No changes could be noted until the temperature was raised to within about 40° F. of the temperature that killed the seed. When this point was reached the endosperm began to darken, oils exuded, and the outer seed coat dried very noticeably. With the higher temperature the other seed coats also showed effects of drying. The intensity of all these changes was directly related to the degree of heat applied.

In the forest floor the stored seed is, of course, surrounded by different conditions from those of the oven. In order, therefore, to ascertain the degree of protection afforded to seed during a slash fire Douglas-fir seed was artificially stored in four locations in a heavy Douglas fir-cedar-hemlock slash near the Wind River forest experiment station. The stations were selected in mineral soil in the middle of a skid road, in a rotten log, in mineral soil under duff, and in the duff. Temperature readings were taken at each station during the fire. The slash was burned on June 27, 1919, with a very hot fire, and resulted in as clean a burn as may be expected in this type of slash. (Pl. II.)

[11] Hofmann, J. V. How Fires Destroy Our Forests. American Forestry, vol. 26, June, 1920.

The temperatures were recorded with a Leeds and Northrup potentiometer, which insured accurate records. The germination of seed that passed through the fire is given in Table 6.

TABLE 6.—*Germination from Douglas-fir seed stored in slash during fire.*

	Number of seeds in sample.	Number of seeds germinated in nursery.	Percentage germinated.	Extreme temperatures during fire.
				°F.
Station 1. Under 1 inch of mineral soil in skid road	9,104	2,082	22.9	75
Station 2. 1¼ inches under surface of rotten log	6,751	1,354	20.1	65
Station 3. In mineral soil under 1½ inches of duff; directly under station 4	9,118	1,621	17.8	60
Station 4. Under ¾ inch of duff; directly over station 3	5,235	1,281	24.5	120
Check. Not heated	7,552	2,033	26.9	
Station 5. 30 inches above ground. Directly over stations 3 and 4				850

The relatively low percentage of germination may be attributed to the poor quality of the seed used, as the check tests also show a very low germination.

The temperatures recorded in Table 6 explain some of the conditions found after slash fires in this region. Strips of young growth commonly spring up along skid roads on certain areas, although there may be very little reproduction on the remainder of the area. The records show that any seeds buried by skidding would be protected through the slash fire and would germinate along the skid roads. The same principle holds for areas lightly burned or burned when the duff is moist. When the forest floor is dry practically the only seed protected is that buried deep in the mineral soil.

The moisture content of the soil and duff is a most important factor in protecting the seeds during the fire, as the moisture prevents the duff from burning and reduces the temperature of the duff or soil. The moisture readings taken before and after the fire are given in Table 7.

TABLE 7.—*Moisture content of soil or duff where seed was stored.*

	Percentage of moisture content.	
	Before fire.	After fire.
Station 1. Under 1 inch of mineral soil in skid road	28.81	11.87
Station 2. 1¼ inches under surface of rotten log	81.71	72.78
Station 3. In mineral soil under 1½ inches of duff; directly under station 4	9.19	12.79
Station 4. Under ¾ inch of duff; directly over station 3	58.06	51.76

The fire apparently had some drying effect, as the moisture content at each station, except station 3, was less after the fire. The drying at any of the stations was not pronounced enough to be injurious to the seed.

FIG. 1.—A group of ninety-one 2-year-old Douglas fir seedlings that grew from a store of seeds presumably buried by rodents.

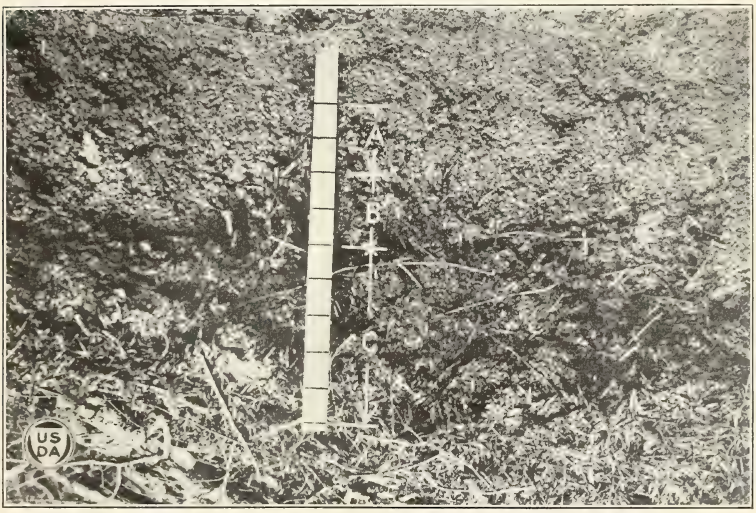


FIG. 2.—Cross section of typical forest floor in Douglas fir type. The following percentages of forest tree seeds were contained in each layer: (A) 80 to 85 per cent of hemlock seed; 80 to 85 per cent of cedar seed; 40 to 50 per cent of Douglas fir seed. (B) 10 to 15 per cent of hemlock seed; 10 to 15 per cent of cedar seed; 35 to 40 per cent of Douglas fir seed. (C) 0 to 5 per cent of hemlock seed; 0 to 5 per cent of cedar seed; 5 to 15 per cent of Douglas fir seed. The rule shown is divided into inches, with the top level with the surface. The kinds and amounts of seed in the layers of vegetable matter and soil explain how fire may change the proportion and kinds of trees by burning to different depths. (See Hofmann, J. V., Young Growth and How It Originates. West Coast Lumberman, Vol. 39, No. 463, Jan. 15, 1921.)

FIG. 1.—A heavy slash left after cutting an overmature stand of Douglas fir, western red cedar, and western hemlock. The white crosses indicate where temperature readings were taken during the slash fire.

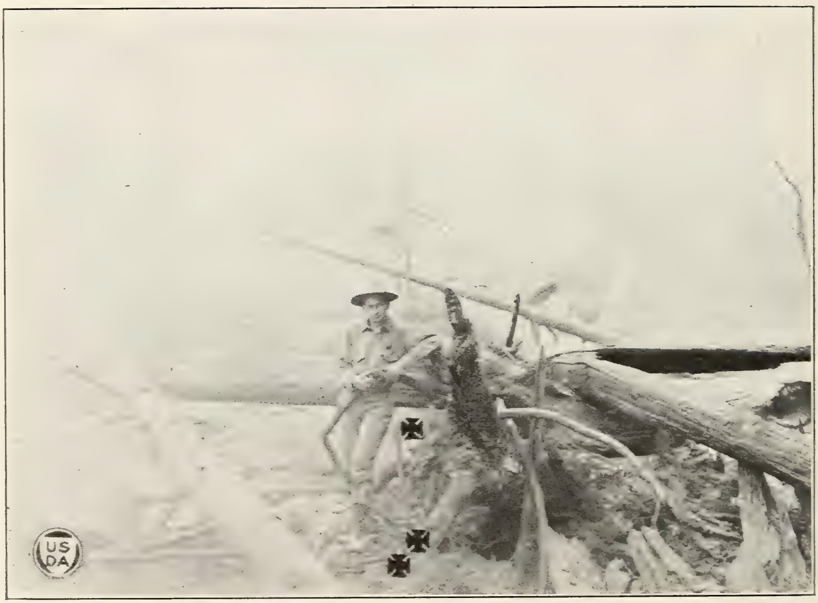
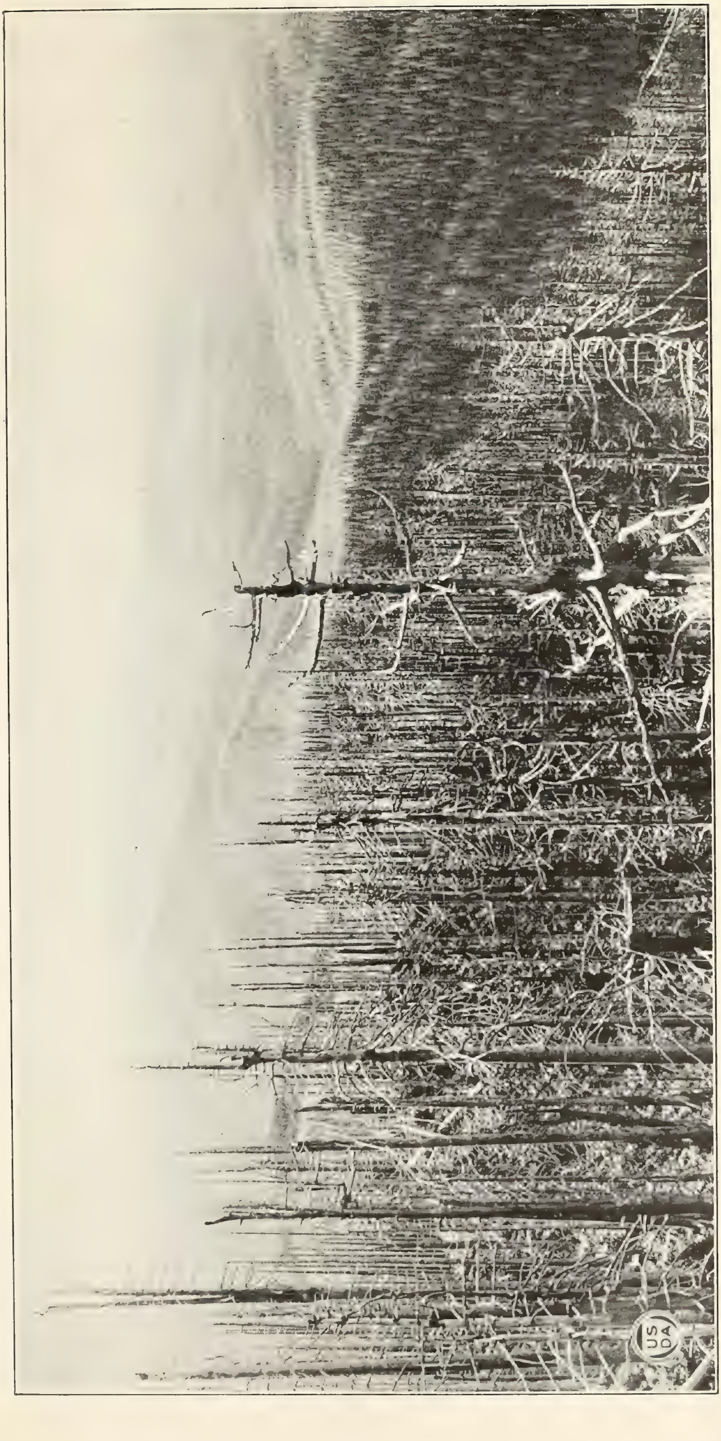
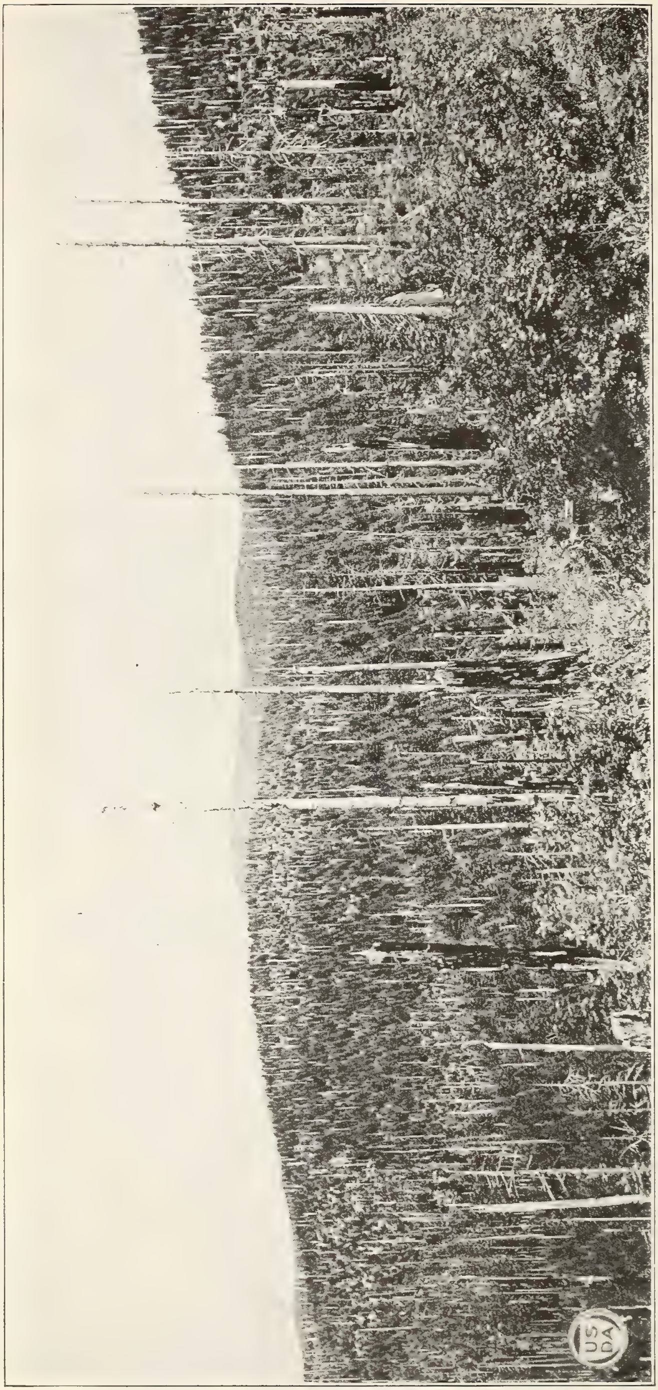


FIG. 2.—After the slash fire. The points at which temperature readings were taken during the fire are marked with black crosses. The temperature at the station 30 inches above the ground reached 850° F.; at the point $1\frac{1}{2}$ inches under the vegetable material the temperature was raised only 48° F.; and at three-fourths inch under the mineral soil, only 5° F.



A mature forest of Douglas fir, noble fir, silver fir, and western hemlock completely killed by one forest fire. This view is a part of the Yacolt burn of 1902, and the area is now covered with a good stand of young growth.



A 20-year-old stand of Douglas fir, with western white pine and other species, which succeeded a single fire on the Paradise Hills, Columbia National Forest. No seed trees are in sight, and none were left after the fire.

VIABILITY OF SEED IN THE FOREST FLOOR.

In order to obtain records under controlled conditions of the longevity of seed in the forest floor an experiment was initiated in the summer of 1916. Thirty cages, 36 by 12 by 6 inches in size, of galvanized wire of ¼-inch mesh, were used. Seed mixed with litter and duff was placed in the cages, which were then closed to exclude rodents, and placed in the forest at different localities. About 8,000 Douglas-fir seeds were stored in each cage.

In the spring of 1917 three of the cages were taken up and germination tests were made of their contents. A germination of about 15 per cent was secured during the summer of that year. When the cages were examined in place in the forest on July 6, 1917, it was found that rodents had dug around them in the attempt to get to the seed, and the burrows in many cases were left open. Along the edges of these burrows, where aeration and warmth had reached the seed in the cages, a vigorous germination was noted. Germination tests in 1918 of this same seed resulted in very few seedlings, and no germination was secured from the stored seed in later years.

This experiment proved conclusively that through the first year the seed in the forest floor remains sufficiently viable to produce good stands of reproduction and that some seeds remain viable until the second season. It is also known that seed remains viable in the forest floor much longer than two years and still produces good stands of young growth. The failure of germination in this experiment may be attributed to the artificial conditions of storage as compared with the condition of seed stored by rodents or in the cones.

Seed stored in the cones at the time of ripening or later is under more favorable storage conditions, especially in the matter of protection from fire. Before the cones open, their scales afford effective protection to seed exposed to forest or slash fires. Cone scales are excellent insulation while the cones are still sealed, for a hot fire of short duration does not open the cones and the seeds escape the fire. The resistance to heat of seeds in unopened cones is shown in Table 8.

TABLE 8.—*Effect produced on Douglas-fir seed by the heating of the cones.*[1]

Temperature outside of cone.	Temperature in degrees Fahrenheit inside of cone after exposure for the indicated number of minutes.								Percentage of weight lost in moisture during heating.	Percentage of germination of seed.
	1	3	5	6	7	10	11	15		
°F.										
700	78	105			175		183	190	50.3	54
800	81			120		165		210	56.1	61
900	80			167		180		230	55.0	37
1,000	97			180					51.6	16
1,100	101		196						39.0	41
1,400	190								42.0	0

[1] Sixty-four tests of individual cones were made, from which the series given in Table 8 is selected to show the effect of the range of temperature from below the ignition point of Douglas-fir wood to a point higher than that ordinarily reached in slash fires or fires that have air drafts mixed through flame, as do forest fires.

While a crown fire is traveling the flame remains in a single crown from about 15 seconds to a minute, with a temperature of 900° to 1,100° F. The ignition point of Douglas-fir needles is 650° F., and at 900° F. the fire spreads rapidly through green needles. A comparison of these figures shows that mature seed would live through the fire if the seed were in cones on the trees.

ORIGIN OF YOUNG GROWTH.

In the Douglas-fir region of Oregon and Washington conditions are little less than ideal for the replacement of the forest by natural means, providing the harvesting of the crop and fire protection are properly managed. The Douglas fir can dominate all its competitors in this region, except under unusual conditions, and these conditions, fortunately, can be controlled by man. Fire is the most destructive agent at work in the forests, and yet it is responsible for retaining the Douglas-fir forests in some localities. The effects of fire on the Douglas-fir forests have been determined by a thorough analysis of the results of various types of forest and slash fires. Some of the most terrific fires of the Pacific Northwest have failed to wipe out the Douglas-fir forests, and splendid stands of young growth now clothe the areas that were burned.

DISTRIBUTION OF YOUNG GROWTH AFTER ONE FIRE IN A MATURE FOREST.

The Columbia burn (locally known as the Yacolt burn) afforded an excellent opportunity for the study of the origin and distribution of young growth following a single fire in a mature forest. The Columbia fire burned northward from the Columbia River in the Columbia National Forest in southern Washington over an area of about 250,000 acres in the western foothills of the Cascade Mountains at elevations of 500 to 4,000 feet (Pl. III). At the lower altitudes the forest traversed by the fire was the Douglas-fir type, which includes Douglas fir, western hemlock, western red cedar, western white pine, and grand fir (*Abies grandis* Lindl.). Above 1,100 feet silver fir makes its appearance, and then noble fir; and at about 3,000 or 3,500 feet the forest develops into the true fir type, composed almost entirely of noble and silver fir, with a slight admixture of western white pine and Douglas fir. Pacific yew (*Taxus brevifolia* Nutt.) is distributed almost throughout the forest, avoiding only the subalpine summits of the higher ridges. Dwarf juniper (*Juniperus communis* L.), on the other hand, is restricted to the subalpine summits.

The fire occurred from September 8 to 12, 1902, following an exceptionally dry season, and driven by a dry southeast wind it traveled to the northwest. So far as can be determined from local information it progressed at a maximum rate of perhaps 8 miles an hour during the time it was doing the most damage. No portion of the area studied had been burned over by a second fire. The burn was studied 11 years after the fire occurred.

The main feature of interest found on the burn was the good stand of young growth which almost uniformly covered the area and consisted of the same species as those which made up the burned forest. The presence of this reproduction is obvious to anyone passing through the area, but the reason for its appearance after so severe a fire has always been open to conjecture. The problem, then, was to determine the history of the reproduction and, so far as possible, to account for its distribution.

An arbitrary section, chosen to include Lookout Mountain, was studied intensively by a gridiron system of belt transects, which were run 2½ chains[12] apart over the entire section. Then, with this section as a hub, a township surrounding it was studied extensively. For this study eight transects were run radially from the centers of the four sides and from the four corners of the section to the corresponding points in the township. Wherever a solid body of green timber was encountered the transect was discontinued. These belt transects served effectively to disclose the distribution of reproduction over the entire township. The plan of the survey is shown in Figure 3. The lines radiating from the center section represent the transects which were run in making the study of the township.

There was little young growth on the south and east slopes of Lookout Mountain, and such as did occur was confined to the draws below the barren slopes. On the north and west slopes, however, it was uniformly scattered. This distribution of the young growth is due to the local topography. The fire approached the mountain from the southeast and swept up these slopes with unusual intensity. After the fire the south and east slopes were hot, dry sites and were consequently unfavorable to the establishment of seedlings. On the other hand, on the north and west slopes not only was the fire less intense, but the site was inherently more favorable to seedling growth.

The most significant facts are found in the distribution of the age classes and their relative proportion, as shown in Table 9. This table shows that 58.9 per cent of all Douglas-fir seedlings germinated the first year after the fire, 28.7 per cent 2 to 6 years after the fire, and 12.4 per cent 7 to 11 years after the fire.

TABLE 9.—*Classification of young growth according to age classes and distribution on section studied in Yacolt burn.*[a]

Species.	Distance from seed trees.	Percentage of total area examined included in each distance.	Percentage of total number of seedlings in each age class found within each distance. Time of germination. First year after fire.	2 to 6 years after fire.	7 to 11 years after fire.	Percentage of all seedlings found, according to age classes. Time of germination. First year after fire.	2 to 6 years after fire.	7 to 11 years after fire.
	Chains.[b]							
	Over 10	79.0	61.1	38.2	0.7			
Douglas fir	6 to 10	9.7	48.1	33.3	18.6	58.9	28.7	12.4
	0 to 5	11.3	67.6	14.6	17.8			
	Over 10	100.0	15.8	84.2	....			
Western white pine	6 to 10	....	....	....	....	15.8	84.2	....
	0 to 5	....	....	....	....			
	Over 10	64.2	96.0	3.3	.7			
Noble fir	6 to 10	20.4	90.0	5.4	4.6	87.5	6.0	6.5
	0 to 5	15.4	76.5	9.4	14.1			
	Over 10	56.6	87.9	10.2	1.9			
Silver fir	6 to 10	24.4	71.5	18.7	9.8	71.5	17.3	11.2
	0 to 5	19.0	55.1	22.9	22.0			
	Over 10	92.0	36.8	57.8	5.4			
Western hemlock	6 to 10	8.0	....	76.9	23.1	18.4	67.4	14.2
	0 to 5	....	....	....	....			

[a] The total area included in transects was 18.6 acres.
[b] One chain equals 66 feet; 10 chains equal one-eighth mile.

[12] One chain equals 66 feet.

The proportion of age classes shows that about one-half of the total Douglas-fir reproduction started the first year after the fire, about one-third from 2 to 6 years, and the remainder from 7 to 11 years after the fire. The decrease in germination of seed throughout the section after the first few years subsequent to the burn and the small percentage of the young age classes found at more than 10 chains from seed trees indicated that the remaining seed trees had not been an important factor in the restocking of the area, especially at distances over 10 chains from seed trees.

These facts are supported by the records of the township study given in Table 10.

TABLE 10.—*Classification of young growth according to age classes and distribution on township studied in Yacolt burn.*[1]

Species.	Distance from seed trees.	Percentage of total area examined included in each distance.	Percentage of total number of seedlings in each age class found within each distance. Time of germination. First year after fire.	2 to 6 years after fire.	7 to 11 years after fire.	Percentage of all seedlings found, according to age classes. Time of germination. First year after fire.	2 to 6 years after fire.	7 to 11 years after fire.
	Chains.[2]							
Douglas fir	Over 10	89.9	80.6	7.0	12.4			
	6 to 10	4.6	68.5	14.4	17.1	68.0	11.6	20.4
	0 to 5	5.5	54.9	13.4	31.7			
Western white pine	Over 10	98.0	25.3	74.7	....			
	6 to 10	1.0	20.0	80.0	....	21.8	78.2	....
	0 to 5	1.0	20.0	80.0	....			
Noble fir	Over 10	89.7	94.1	3.0	2.9			
	6 to 10	5.5	90.9	2.2	6.9	84.1	4.7	11.2
	0 to 5	4.8	67.2	8.8	24.0			
Silver fir	Over 10	85.2	93.5	5.1	1.4			
	6 to 10	5.5	75.0	25.0	....	82.8	16.7	.5
	0 to 5	9.3	80.0	20.0	....			
Western hemlock	Over 10	78.4	26.5	53.0	20.5			
	6 to 10	9.3	25.0	45.8	29.2	23.6	50.1	26.3
	0 to 5	12.3	19.3	51.6	29.1			

[1] The total area included in transects was 32.25 acres.
[2] One chain equals 66 feet; 10 chains equal one-eighth mile.

The Douglas-fir germination over the entire area in the first year after the fire was more than half of the total germination. The fact that the germination after the second year following the fire was confined largely to within 10 chains of seed trees indicated that the remaining seed trees were not casting seed over the burn as a whole, as germination conditions were still favorable when the examination was made 11 years after the fire.

The section and township records demonstrate that reproduction which germinated 7 to 11 years after the fire is limited to the vicinity of seed trees or to localities which seed can reach because of favorable topography. Trees on a hillside above a canyon disseminate their seed over a wider range of territory than trees on level ground, for the seed can be blown down into the canyon and across to the opposite slope.

There were no Douglas fir seed trees on the section studied (see fig. 3), except a single broken-topped one, but there were Douglas

20a

R

re shown

FIG. 3.—Map of township in Yacolt burn. Transects and reproduction after fire are shown.

60634—24. (Face p. 20.)

fir seed trees within 2 or 3 chains of the northeast corner of the section on the northwest slope of Little Lookout Mountain. These trees were from 100 to 300 feet above the areas on which germination occurred 7 to 11 years after the fire; hence it is entirely possible that they were responsible for the occurrence of this age class in the northern part of the section. The limited distribution of this same age class, with reference to seed trees and topography, was consistent throughout the section and was particularly conspicuous at several points in the township. (Fig. 3.)

The transect from the west-central point of the section passed within 2 chains of green timber. The influence of this timber is shown in Figure 3 by the appearance of young growth which germinated 7 to 11 years after the fire for a distance of a few chains from the seed trees in Texas Gulch. The remainder of the transect had a scattered stand of reproduction of the older age classes. A very dense stand occurred in Poison Gulch almost a mile from the nearest seed trees. This same condition is illustrated on the southwest transect, where the young growth of the older classes is very heavy along the north slope of Bear Creek Canyon at a distance of more than a mile from the nearest Douglas-fir timber. As the transect approaches the timber at the top of the ridge, older seedlings are again found scattered here and there, and it is only close to the edge of the timber that the younger seedlings begin to appear at all. This peculiar distribution of the reproduction may be observed on all of the transects, and shows definitely that the green timber remaining after the fire has had little influence on the general occurrence of the Douglas-fir reproduction over the burn.

The foregoing facts first cast a doubt upon the long-accepted theory of the restocking of large forest burns by the process of wind dissemination of seed and finally proved it untenable. As the study progressed and this fact grew steadily more convincing, the question naturally arose, "What was the source of seed for all this reproduction?" The answer to this question developed with the accumulation of evidence throughout the burn. It was found that the reproduction most often occurred, not in a solid unbroken cover, but in different-sized patches with irregular and ramifying boundaries. Where the reproduction was lacking, the ground was covered with grasses, herbaceous plants, and shrubs, evidencing an uninterrupted growth since the burn was formed. The occurrence of these two types of cover made an interlaced pattern over the entire burn, although one type or the other often expanded solidly over a slope or basin many acres in extent. Everywhere the feature that was most striking was the sharp line of demarcation between the reproduction and the grass areas. For all its tortuous windings the boundary was always distinct.

Obviously such a condition could not have resulted from natural seeding, but must rather have been produced by some force acting on the surface of the ground. The idea of ground fire suggested itself. One who has seen ground fire burning in forest duff will remember that it burns irregularly, leaving here an island and there forming a deep bay between two points of unburned ground. When at length the smoldering fire is stopped, the result is just such a mosaic of burned and unburned surface corresponding to the mosaic of reproduction and grass described above. A representative spot in the Columbia burn is illustrated by Figure 4.

The most severe ground fires occur on dry sites and in localities where there is heavy litter and duff. They occur also where the flames sweep the surface, as where a fire runs up hill. Under these conditions the soil is severely heated. The irregularity of the young growth on all sites led to the conclusion that where fire consumed

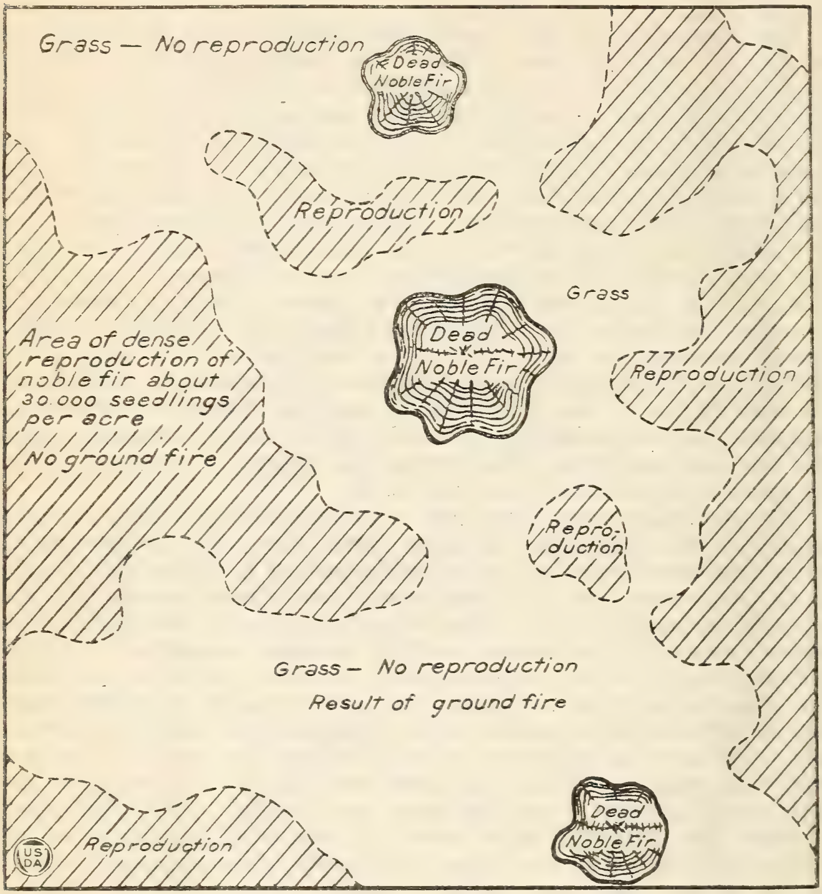


FIG. 4.—Effect of ground fire on distribution of young growth.

the duff and heated the soil no reproduction was possible except close to seed trees.

With the recurrence of irregular patches of reproduction in areas where the litter and duff were not completely destroyed, and in moist places where the forest floor had not been heated, it was concluded that the seed from which the young growth sprang on the Yacolt burn and on other similar burns that were studied, must have been stored in the duff or soil before the fire. (Pl. IV.)

DISTRIBUTION OF YOUNG GROWTH AFTER ONE FIRE IN FORESTS OF DIFFERENT AGE CLASSES.

The Cispus fire of 1902 afforded an opportunity to study an area in which a single fire burned in two distinct age classes of forest. This area was in the region where the Tower Rock ranger station on the Rainier National Forest now stands. One age class was a mature Douglas-fir forest, and the other a second-growth stand of pole-sized, nearly pure Douglas fir about 40 years old. The young forests that followed after burning in each of the two age classes were strikingly different.

In the mature Douglas-fir forest the conditions after the burn practically duplicated the conditions found on the Columbia burn. There was the same distribution of dense and sparse reproduction independent of the position of seed trees; there was essentially the same proportion of age classes in the reproduction, evidencing the greatest germination during the first two years after the fire; there was the same alternation of patches of the original brush cover and of reproduction, outlining the limits of the irregular ground fire. There was, moreover, abundant proof of the inadequacy of the surviving seed trees to restock a burned forest area of large extent. There were left on this burn numerous groups of living seed trees of Douglas fir and minor species ideally placed for a study of their influence in reseeding the area. In spite of the most favorable conditions of site for the germination and establishment of seedlings, it was invariably found that 1, 2, and 3 year old seedlings were limited to a radius not greater than 3 or 4 chains from seed trees. On the other hand, seedlings 10 and 11 years old were found everywhere, even at 12 chains, the maximum distance from seed trees attainable in the area.

The destruction of a portion of the pole-sized stand of Douglas fir by the fire of 1902 produced peculiar conditions. When examined in 1914 the ground was occupied by a dense cover of shrubs and ferns which grew up through a network of dead-and-down logs of small diameter. Reproduction occurred on this area in spite of the heavy brush cover, but it was comparatively scarce. The reproduction, in its struggle against the surrounding brush, developed the tall, lank "shade form" common to any thicket or forest-grown plant. The older seedlings occurred independently of the position of seed trees, but showed a tendency to be limited to moist sites, such as occur in ravines and hollows, where the conditions were most favorable immediately after the fire for germination and establishment. The younger seedlings (1 to 5 years old), however, showed an increase in density in the neighborhood of seed trees. Several seedlings of this class were found dead as a result of excessive drought and heat in open places, but they were rarely found either living or dead at distances over 6 chains from seed trees.

The occurrence of two distinct age classes of seedlings and their positions in the burn with reference to seed trees indicate again that there were two sources of seed, namely, seed trees and the duff and soil in which seeds were stored. The reasons for the failure of seed trees to restock the burn have been discussed before. The scarcity of seedlings from duff-stored seed, however, presented a problem peculiar to this burn. The dense cover of shrubby and herbaceous growth on the area might account for a scarcity or absence of seedlings from "wind-blown" seed, but it would not account for the scarcity of seedlings from stored seed. Reproduction from stored seed, as a rule, starts at the same time as the brush on the burn, and does not come in after the brush has taken possession of the ground. Hence, the reproduction has merely to hold its own in height growth with the brush, and this it has frequently proved itself able to do.

The reason for the scarcity of reproduction from stored seed must be sought in the condition of the stand. The fire burned, not in an old virgin forest, but in a young forest, which was itself successor to a burned mature forest. The earlier fire (1860) killed most of the veteran trees which were the chief source of seed then stored in the forest floor. From the stored seed of the old forest there resulted a thrifty second growth of almost pure Douglas fir. How complete this stand was could not be determined; it is likely that there were openings resulting from ground fire in parts of the original burn. In 1902, at a time when this young forest was seeding, but long before it had shed enough litter on the ground for the storage of its seed this forest also was destroyed by fire. In the hot fire of 1902 some of the duff was undoubtedly burned and consequently some of the stored seed. The result of this combination of circumstances was the occurrence of scattered, inadequate reproduction amid a rank growth of brush and weeds. The reproduction was more plentiful in moist or depressed spots, where the duff had in a large measure, escaped the ground fire and provided favorable conditions for the germination and establishment of seedlings after the fire.

The findings on the Cispus burn corroborated those established on the Columbia burn, and brought out additional facts regarding the effect of the original stand upon the reproduction that follows after a single fire.

Where the young stand of timber was destroyed by fire, only a thin stand of reproduction occurred on the burn. The reason for the light reproduction was found in the small accumulation of duff on the floor of the young forest, and in the smaller accumulation of seed in the duff which resulted from the limited production of seed by the young trees.

EFFECT OF SOIL CONDITIONS ON DISTRIBUTION OF YOUNG GROWTH FOLLOWING ONE FOREST FIRE.

Even where a mature forest of uniform type is burned by a single fire, densely stocked areas of young growth may occur alternately with sparsely stocked or barren areas.

Where reproduction does not follow the first forest fire the explanation often lies in the condition of the soil. An extensive area on which practically no young growth followed the first fire was found in the Cispus burn of 1910 along the Johnson Creek Trail. The area was characterized by light volcanic ash soil, which, no doubt, was the chief reason for barrenness of the area after one fire. This type of soil is so dry and porous that a fire will heat it, burn all the duff, and even destroy the seed that may be buried in the mineral soil, so there is no possibility of reproduction from seed stored in the duff. If a fire occurs in this type during a period when there is no mature seed in cones on the trees there is little possibility of seed being left to restock the area.

When the loose mineral soil is exposed it becomes dry, and the establishment of seedlings, even in the vicinity of trees from which seed is distributed after fire, is very rare. Seedlings which do become established usually occur under logs or, as has often been noted, in the hollows of burned-out stumps, where the moisture is retained.

Another large burn known as the Two Lakes fire of July, 1918, in the upper Cispus region, showed a striking correlation of soil conditions and distribution of young growth. The forest floor under mature timber in this upper region is quite different from the forest floor of the lower valleys. The layer of dry needles and moss was completely consumed in the drier localities and the loose, porous, ashy soil beneath was severely heated. Stored seed could not survive such severe burning, so that what restocking there was had to come from seed from the remaining living trees.

Although 1918 was a good seed year for all of the species of this region the condition of the area after the burn showed that the distribution of the young growth was not dependent on the remaining seed trees. On the other hand, on areas where the entire forest had been killed by a crown fire, a consistent relation between the condition of the soil and the occurrence of young growth was found. The dry slopes and ridges were barren or very sparsely stocked, and the moist valleys and north slopes were well stocked. In some places there were as many as 40,000 seedlings to the acre. The relation between soil conditions and distribution of young growth is shown by a typical transect which illustrates conditions on the burn as a whole. (Table 11 and fig. 5.)

TABLE 11.—*Number of seedlings per acre found on a belt transect one year after mature timber had been killed by the Two Lakes fire of July 12–18, 1918.*

Chains[1] distant from green timber.	Number of seedlings per acre.						
	Douglas fir.	Noble fir.	Silver fir.	Western hemlock.	Western red cedar.	Engelmann spruce.[2]	Total.
1	320		240	80		80	720
2	80	80		80		80	320
3				80			80
4	80					80	160
5				80		80	160
6							0
7	80						80
8					80		80
9			80	160			240
10							0
11				320			320
12				240			240
13							0
14	320						320
15							0
16							0
17							0
18							0
19							0
20							0
21				80			80
22							0
23							0
24				80			80

[1] 1 chain equals 66 feet; 40 chains equal one-half mile.

[2] Picea engelmanni Engelm.

TABLE 11.—*Number of seedlings per acre found on a belt transect one year after mature timber had been killed by the Two Lakes fire, etc.*—Continued.

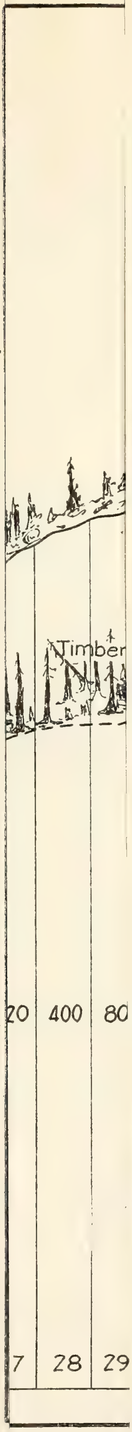
Chains distant from green timber.	Number of seedlings per acre.						
	Douglas fir	Noble fir.	Silver fir.	Western hemlock.	Western red cedar.	Engelmann spruce.	Total.
25	...	...	...	80	...	...	80
26	160	...	...	80	...	...	240
27	240	80	...	...	...	...	320
28	160	...	...	240	...	...	400
29	80	320	...	400	...	...	800
30	160	...	...	160	80	...	400
31	240	...	...	560	240	...	1,040
32	...	...	...	...	...	...	0
33	160	...	80	400	...	...	640
34	400	...	240	880	560	160	2,240
35	480	...	...	...	...	80	560
36	480	80	80	...	...	160	800
37	400	...	80	...	80	80	640
38	480	...	...	240	...	320	1,040
39	560	80	320	80	...	720	1,760
40	800	240	80	1,040	...	400	2,560
41	240	...	80	1,120	320	400	2,160
42	240	160	240	2,880	240	1,040	4,800
43	1,120	...	560	160	240	1,040	3,120
44	160	...	...	880	1,200	80	2,320
45	80	80	960	2,160	4,800	320	8,400
46	720	560	3,200	9,840	19,200	640	34,160
47	400	560	1,680	1,0640	10,560	1,120	24,960
48	400	160	640	880	240	560	2,880
49	160	160	240	800	240	320	1,920
50	1,120	80	720	880	160	...	2,960
51	880	...	400	160	...	80	1,520
52	240	...	240	160	80	...	720

The scattered stand of young growth on this transect adjacent to the green timber, and the alternation of sparse stands and barren areas up to 25 chains from the green timber are evidence that the seed was not distributed from the remaining seed trees, and that the dense stands of reproduction that occurred farther out in the burn were due to seed that was on the area before the fire and lived through the fire.

From chains 38 to 51 the soil was moist, and conditions for the protection of seed during the fire and for the establishment of seedlings after the fire were very favorable. These, no doubt, were the principal factors responsible for the dense stands of young growth that were found in this locality. The barren areas nearer to the green timber lie on more exposed slopes, where the soil was susceptible to heating during the fire and unfavorable to the establishment of seedlings after the fire. Often there was a pronounced line of demarcation between the good stands of young growth and the barren areas along moist draws or slopes, as shown in Figure 5.

EFFECT OF GROUND FIRE ON CHARACTER AND DENSITY OF YOUNG GROWTH.

A ground fire may be the decisive factor in the regeneration of the forest. Where it creeps through the duff and litter it destroys nearly all the seed in the forest floor and leaves a bed of deep ashes and exposed mineral soil. If a ground fire occurs in the fall when the seed is about mature or before it falls from the trees, the new crop of seed produces a dense stand of seedlings in the immediate vicinity of the seed trees.



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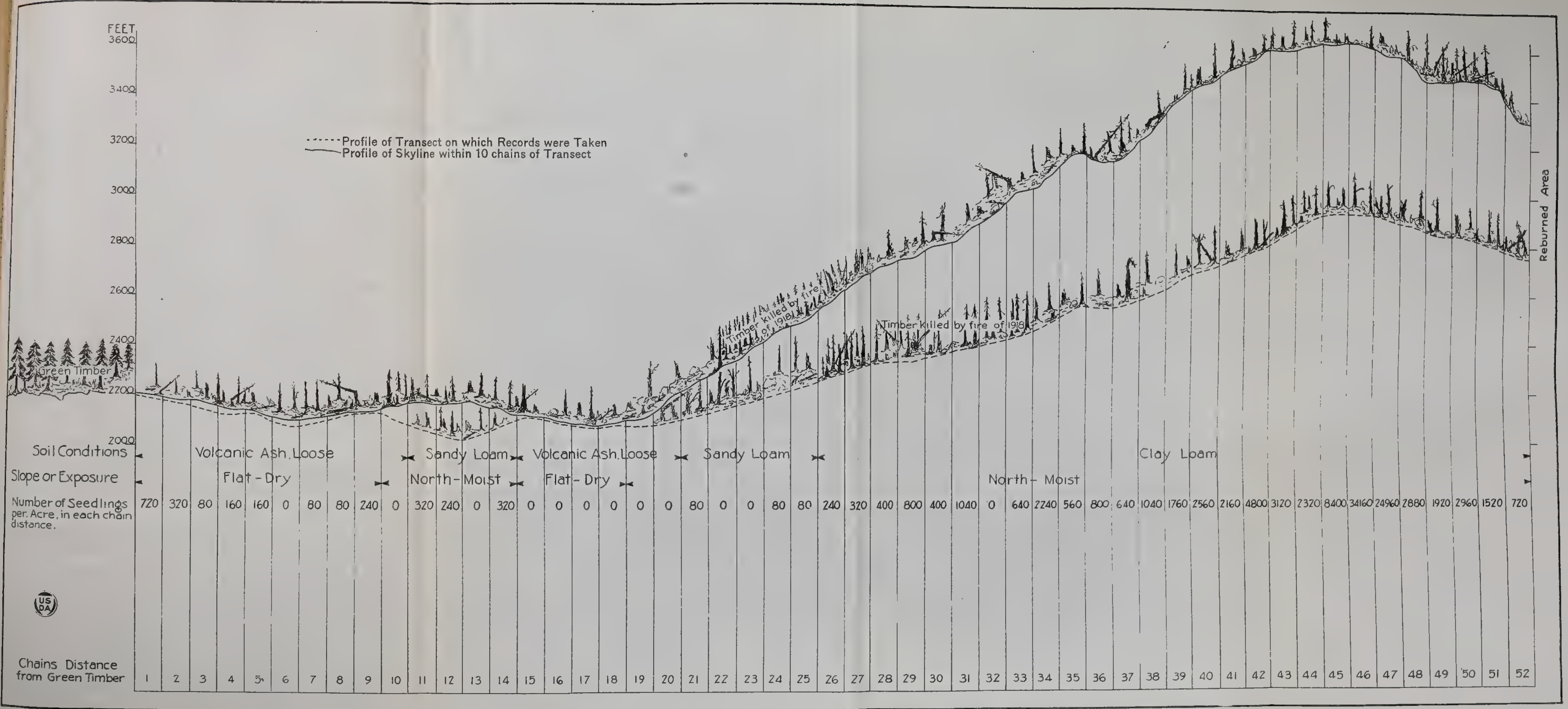

FIG. 5.—Effect of soil conditions on distribution of young growth on the Cispus area where a mature forest was killed by a single fire in July, 1918. Examined September, 1919.

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A fire that occurred near Guler, Wash., on September 2, 1915, ran through the crowns of medium-aged Douglas-fire trees that were heavily laden with mature cones, and killed but did not burn them severely. At the same time, a severe ground fire burned the deep layer of litter and duff and undoubtedly heated the soil sufficiently to destroy practically all of the seed stored in the forest floor. Counts of young growth two years later showed that there were 17,600 Douglas-fir seedlings per acre, and 98.8 per cent of them came up the first year after the fire. Under these conditions, sometimes found after large forest fires, the young growth may come from seed in the cones at the time of the fire. That seed will live in cones during a crown fire has been proved experimentally. (Pl. V, fig. 1.)

If a ground fire occurs in a mixed forest of Douglas fir, western red cedar, and western hemlock, when the mature seed is on the trees, usually the greatest part of the resulting young growth is western red cedar and western hemlock, because of the large amounts of seed produced by these species as compared with Douglas fir. The dense stand of seedlings may survive through the first season, but in the succeeding years the Douglas fir is severely handicapped. If the scorched canopy of the forest remains even for a year after the fire, the shade is too dense for the Douglas fir seedlings to gain a foothold, and they are crowded out of the stand. The mature Douglas fir trees generally are not killed by this type of fire on account of the thick root bark at the crown of the roots, but the thin bark at the root crown of the western red cedar, western hemlock, noble fir, and silver fir leaves these species easy victims. The remaining green Douglas-fir trees may continue to produce seed, but the shade of the dead and living trees is too dense for the success of the Douglas fir seedlings. Consequently the shade-enduring species, such as western red cedar and western hemlock, have the advantage; an understory of these species develops and ultimately changes the forest to the cedar-hemlock type. (Pl. V, fig. 2.)

In places where a ground fire has occurred, counts on plots have shown stands containing more than 1,000,000 seedlings, 1 and 2 years old, to the acre, with only 5 to 10 per cent of Douglas fir. The Douglas-fir seedlings were tall and weak, and seemed to have little chance of survival, and observation in later years showed that they did not survive.

SEED STORED IN THE FOREST FLOOR IS THE PRINCIPAL SOURCE OF YOUNG GROWTH THAT FOLLOWS AFTER ONE FOREST FIRE.

Although young growth from different sources of seed follows after various types of forest fires, the seed in the forest floor before the fire is obviously the most important factor in restocking the burned areas. As a general rule, restocking may be expected after a single burn; but such factors as soil, condition of forest floor, and type of fire may cause exceptions to the rule. The general restocking after one burn is shown in the summary of a representative number of transects that were taken in areas burned under different conditions and in different places. This summary appears in Table 12. The averages are based on the number of seedlings found in each chain-length of transects that were run from the edge of green timber to a distance of 120 chains out into the burns.

TABLE 12.—*Average number of seedlings per acre in each chain distance from timber on areas where mature timber was entirely killed by one forest fire.*[1]

(Ages of burns varied from 2 to 11 years, with corresponding variation in ages of seedlings.)

Chains[2] distant from green timber.	Number of seedlings per acre.				
	Douglas fir.	Western red cedar.	Western hemlock.	Noble fir.	Total.
1	1,341	210	713	242	2,506
2	1,256	313	1,619	259	3,447
3	769	573	719	254	2,315
4	753	72	679	305	1,809
5	678	60	456	314	1,508
6	676	105	1,132	260	2,173
7	487	380	1,249	223	2,339
8	371	300	507	173	1,351
9	345	230	563	183	1,321
10	290	230	1,193	112	1,825
11	237	200	350	155	942
12	261	180	282	140	863
13	228	140	230	156	754
14	333	130	177	113	753
15	240	120	330	140	830
16	160	145	114	75	494
17	202	130	118	95	545
18	202	140	120	142	604
19	144	180	231	90	645
20	208	170	302	152	832
21	245	160	267	93	765
22	210	155	393	46	804
23	161	160	270	68	659
24	288	155	240	16	699
25	243	130	294	43	710
26	157	140	280	20	597
27	222	180	253	32	687
28	187	170	204	30	591
29	162	190	313	75	740
30	165	200	323	62	750
31	183	380	186	73	822
32	217	270	84	80	651
33	155	280	150	47	632
34	253	575	313	90	1,231
35	297	210	136	72	715
36	274	205	100	103	682
37	325	200	222	96	843
38	293	190	276	78	837
39	334	180	270	95	879
40	555	170	543	172	1,440
41	246	315	585	55	1,201
42	235	270	1,480	128	2,113
43	682	320	80	42	1,124
44	213	805	440	57	1,515
45	190	2,555	1,080	107	3,932
46	478	9,830	4,920	338	15,566
47	315	5,440	5,320	340	11,415
48	308	300	440	118	1,166
49	225	280	413	181	1,099
50	696	280	456	135	1,567
51	586	170	90	84	930
52	240	220	87	90	637
53	237	(3)	7	203	447
54	263	....	30	220	513
55	273	....	40	273	586
56	280	....	67	273	620
57	267	....	53	240	560
58	263	....	47	197	507
59	237	....	37	257	531
60	273	....	40	280	593
61	360	....	47	153	560
62	373	....	53	167	593
63	387	....	60	153	600
64	353	....	47	127	527

[1] Based on 18 belt transects 8¼ feet wide, each 120 chains long, making a total of 27 miles of line. Transects are taken from burned areas examined on the Columbia, Rainier, Oregon, Snoqualmie, Santiam, and Crater National Forests.

[2] 1 chain equals 66 feet; 80 chains equals 1 mile.

[3] A sufficient number of areas more than 52 chains from green timber were not examined in the western red cedar region to arrive at a fair average.

TABLE 12.—*Average number of seedlings per acre in each chain distance from timber on areas where mature timber was entirely killed, etc.*—Continued.

Chains distant from green timber.	Number of seedlings per acre.				
	Douglas fir.	Western red cedar.	Western hemlock.	Noble fir.	Total.
65	360		40	163	563
66	340		37	170	547
67	393		27	173	593
68	423		20	57	500
69	307		13	47	367
70	373		7	43	423
71	383		3	20	406
72	407		20	23	450
73	693		13	43	749
74	613		20	67	700
75	667		27	147	841
76	683		40	167	890
77	777		37	130	944
78	770		30	150	950
79	1,243		27	360	1,630
80	867		40	353	1,260
81	790		33	333	1,156
82	1,073		33	347	1,453
83	973		20	303	1,296
84	947		10	350	1,307
85	733		57	80	870
86	613		37	53	703
87	697		40	50	787
88	693		33	57	783
89	793		47	63	903
90	773		40	77	890
91	900		160	107	1,167
92	970		120	107	1,197
93	1,093		133	130	1,356
94	953		127	140	1,220
95	880		140	127	1,147
96	910		137	133	1,180
97	1,087		113	257	1,457
98	1,393		133	247	1,773
99	1,457		227	233	1,917
100	1,150		207	240	1,597
101	1,093		213	280	1,586
102	1,023		140	233	1,396
103	3,027		193	333	3,553
104	3,447		200	400	4,047
105	4,360		393	447	5,200
106	5,840		400	447	6,687
107	4,907		353	260	5,520
108	5,377		327	477	6,181
109	4,647		420	140	5,207
110	8,227		427	137	8,791
111	9,363		320	373	10,056
112	10,793		260	303	11,356
113	11,460		230	240	11,930
114	6,497		213	260	6,970
115	4,237		257	420	4,914
116	3,980		307	367	4,654
117	3,563		260	400	4,223
118	1,583		227	407	2,217
119	1,860		197	363	2,420
120	2,180		113	430	2,723

An area that contains 500 or more seedlings per acre requires no additional stocking, but more dense stands up to 1,000 or 2,000 to the acre are desirable in the Douglas fir region. The average stands shown in Table 12 would be satisfactory for the entire region. Actually, however, the stands range from sparse to extremely dense, and a burned region may include some barren areas here and there. No effect on density of stocking can be attributed to green trees left after a fire except within a radius of about 5 chains from the seed trees. Where sparse stands of young growth follow the first fire on areas too distant from green timber for restocking by wind-blown seed it is extremely important to protect the young trees in order that they may serve as seed trees for the area when they reach seeding age. (Pl. VI, fig. 1.)

DISTRIBUTION OF YOUNG GROWTH AFTER TWO OR MORE FIRES ON THE SAME AREA.

Repeated fires on large burns are a more serious menace to a forest cover than the first fire, because if a reburn occurs before the new stand has reached seeding age it may produce an area which will remain barren for an indefinite period. (Pl. VI, fig. 2.)

A number of fires had occurred in the Cispus region on the Rainier National Forest, and consequently it afforded suitable areas for the study of the effects of repeated burnings. Evidence was found of a general fire over the entire region in 1660, and of local fires in 1761, 1874, 1892, 1902, and 1910. During the studies of 1914 the types of forest following these burns were analyzed. On the areas where the forest had reached maturity or had grown to middle age (100 years or more) the same conditions prevailed that were found after one forest fire; that is, a good stand of reproduction followed the first fire, and although the reproduction varied in density, the area could be classed as restocking. In the localities where a second or third fire occurred before the stand reached seeding age, only limited areas were restocking by seeding from the remaining seed trees or stands of timber. This was definitely checked by a series of permanent plots on areas that were burned in 1902, 1915, and 1918. A good stand of young growth followed the 1902 fire where the mature forest had been completely killed. When this young growth was 13 years old, and before it had reached an effective seeding age, it was destroyed by the fire of 1915. The mature Douglas fir trees in the vicinity that had escaped the 1902 fire were not injured by the 1915 fire. This same area was burned by the general fire of 1918, and again the mature trees escaped being killed. Young growth appeared near the seed trees after each fire, but only for distances of 6 chains or less, and very little at more than 4 chains from the seed trees.

Another area near the source of the Cispus River demonstrated the effect of repeated burning. A burn in 1764 was followed by a sparse stand which was reburned in 1870 at the age of 106 years. The burn of 1870 was again restocked with a scattered stand, which in turn was destroyed by the fire of 1910, when the stand was 40 years old. The 1910 burn still remains a denuded area. The explanation of this process of denudation lies in the successive fires that occurred before sufficient duff had accumulated to protect seed stored in the forest floor, and in the porosity of the soil which provided such good drainage that the humus and duff were dried out. Under these conditions the forest floor is usually burned severely; probably all of the litter and duff are consumed, and the soil is heated deeply enough to destroy most of the seed. This process has been noted in other forest types. It occurred again in the same locality during the 1918 fire, which swept over the Cispus and Spring Creek drainages.

The large area burned by the Cispus fire of 1902 was to a great extent covered by young growth, except locally, where subsequent fires burned in 1910 and 1915. On June 27, 1918, a second big fire, which covered about 60,000 acres, swept over this region. While the fire was running up the main Cispus Valley and up the North Fork and Niggerhead Creeks, it traveled at the rate of 3 to 4 miles an hour. It swept through the patches of green timber that had been left by the 1902 fire and entirely killed many of them. The dead snags and down logs in the old burn caused a very hot fire, and when it reached the boundaries of the 1902 fire it usually killed the green timber on a strip from a few chains to over half a mile in width. This fringe of fire-killed timber and patches of timber killed by the 1918 fire that had remained after the 1902 burn provided definite checks on the source of young growth following a first or second fire. The Douglas fir seed crop of 1918, being general and unusually heavy, afforded an excellent opportunity for restocking, because the fire consumed the vegetation on the old burn, and where it killed the green timber left mineral soil, which was an exceptionally good seed bed for the germination of the 1918 seed crop when it matured in the fall. The fire occurred so early in the season, however, that there was no possible chance for seed to mature before the trees were killed in the burn of 1918. Any reproduction found on the area after this fire must of necessity have been from seed that was in the forest floor from previous seed crops, or it must have come from seed blown by wind or carried by other agencies from the adjoining green timber.

The reproduction following the burn of 1902 was 16 years old at the time it was killed by the 1918 fire. A few Douglas firs were found that had been producing cones for two or three years before the fire, but the amount of seed produced on these areas was very small. The mineral soil was either exposed or had a vegetative cover. In the area burned, the loose mineral soil shifted and buried the seed. This has been found to be an important factor in reproduction in some places, and is no doubt one of the underlying causes of the scattered reproduction found in the 1902 burn that was reburned in 1918. Perhaps the most striking features on this area, from the standpoint of reproduction, are the establishment of seedlings where the green timber was killed by the 1918 fire and the practically complete absence of reproduction where the 1902 fire was followed by the 1918 fire.

The studies of 1914 and 1915 provided an accurate history of this area before the big burn of 1918. For this reason the effects of the fire of 1918 could be analyzed without any speculation as to what might have occurred before the fire. The relation of the occurrence of seedlings to the areas of timber killed by the 1918 fire was carefully analyzed by using belt transects, which were run from points out in the 1902 burn to the timber killed in 1918, and through this killed timber to the present stand of green timber.

These transects showed that there was practically no reproduction out in the twice-burned area, and, where the lines approached to within 1, 2, or 3 chains of the edge of the timber killed in 1918 the reproduction appeared. The stands of young growth varied in density from a few hundred to nearly 40,000 to the acre without relation to the remaining green timber, but with a noticeable relation to soil and topographic conditions.

The principal factor in the variation in the density of reproduction apparently was the moisture of the soil. On some of the transect lines dense stands of reproduction were encountered more than half a mile from green timber, either on moist north slopes or in ravines. As these lines crossed dry, exposed slopes or ridges the reproduction became sparse. In some localities seedlings were found either under logs, in hollows, or in other places where there was moisture. The density of reproduction at long distances from green timber was in some places greater than near it. Where the transect lines passed through the 1902 burn into a patch of timber that had been killed by the 1918 fire, and through it into the 1902 burn again, the same conditions prevailed in approaching and leaving the timber killed in 1918 as were found where the lines approached green timber on the edges of the burn; that is, the reproduction was usually found from 1 to 3 chains from the edge of the timber killed in the 1918 fire. Dense stands of young growth were found in the areas of timber

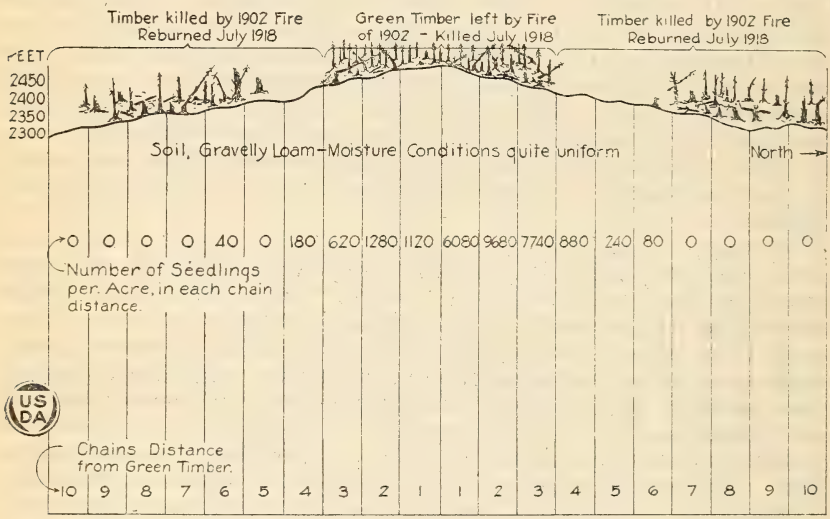


FIG. 6.—Effect of reburning. An area in the Cispus burn of July, 1918, that was restocked from seed stored in the forest floor near seed trees left by the 1902 fire. There were no seed trees within three-fourths mile after the fire of 1918. Young growth that followed the 1902 fire had not reached seeding age in 1918. Such areas were not restocked after the second fire.

killed in 1918; and, as the lines left the killed timber on the opposite side, the same conditions were found to be repeated in inverse order until practically no reproduction was found out in the 1902 burn. (Fig. 6.)

These phenomena are explained by the principles already discussed; that is, the reproduction in this case came entirely from seed stored in the forest floor. There was no possibility of seed coming from cones; there was no evidence of seeding from the remaining timber; consequently, the only other source of seed was the forest floor. The young growth around the edges of the timber killed in 1918 shows the zone of seeding from this green timber before the fire. Although there was no litter and duff in this area, the loose soil covered some of the seed, and large quantities were undoubtedly buried by rodents.

An area in the Wind River Valley of southern Washington, where the timber had been killed by the Yacolt fire of 1902, was covered

FIG. 1.—A mature forest completely killed by a single forest fire. Cones are left on the trees after all needles and small twigs have been burned. Cones of Douglas fir, noble fir, and white pine are shown on the trees. Germination has been obtained from cones that passed through forest fires.

FIG. 2.—Silver fir, western red cedar, and western hemlock trees left after logging. If such trees are killed by the slash fires, they become a fire menace; and if they are left green, they help restock the area, to the exclusion of Douglas fir. They should be cut before the first slash fire. If there was sufficient Douglas fir in the original stand, a good young growth of that species may be secured.

FIG. 1.—A scattered stand of young Douglas fir on a burned area. Such scattered seedlings should be protected, as they are the potential seed trees for the entire area.

FIG. 2.—A good stand of young growth that followed a 1902 fire on the Oregon National Forest was partially destroyed by a 1910 fire. The portion of the stand destroyed in 1910 is not restocking.

FIG. 1.—Group of noble fir, Douglas fir, and western hemlock in unburned slash. There are 27 seedlings per square yard.

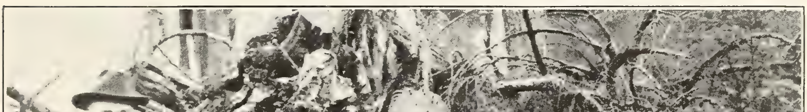


FIG. 2.—An excellent stand of young growth in unburned slash after clear cutting. This area was logged 15 years ago and is now covered with a young forest consisting of about 20 per cent Sitka spruce, 20 per cent western red cedar, 10 per cent Douglas fir, and 50 per cent western hemlock.

FIG. 1.—The effect of a July fire in heavy slash after the cutting of a mature stand of Douglas fir and associated species. A very scattered stand of young growth followed this fire.

FIG. 2.—A pure stand of Douglas fir following clear cutting and a spring slash fire. The young growth is 18 to 20 years old, and there are about 8,000 trees per acre.

with a good stand of young Douglas fir and associated species. In September, 1915, this area was reburned. The second fire did not kill any of the trees that had been left alive by the 1902 fire, but it destroyed all the young growth on the area. Forty-five plots, each 1 rod square, were laid out after the fire of 1915, and definite records were kept of the germination and survival of seedlings following the second burn. Little reproduction was found on the area at distances more than 3 chains from seed trees, although stands of Douglas fir containing 8,640 seedlings per acre followed the second burn at distances within 2 chains of groups of seed trees. A few single green trees were scattered at distances of 15 to 20 chains from the groups of seed trees and near some of the reproduction plots. The plots near these seed trees did not have more seedlings than those at greater distances, although these seed trees were known to have produced seed crops. Undoubtedly the seed crops were gathered and destroyed by rodents. On a near-by flat area, burned at the same time, scattered reproduction occurred under the remaining seed trees, and none at distances of 4 chains or more from them.

On all the areas that have been studied, where two or more fires have occurred, it has been found that the young growth following the second or later fires either occurs only in the immediate vicinity of seed trees, or the seedlings are scattered over great distances but occur only occasionally. Such reproduction may come from seeds that have been transported for long distances by wind or birds, or it may have come from seeds that have passed through exceptionally long periods of dormancy. The averages of the areas studied where reburns have occurred are given in Table 13.

The contrast of the stands of young growth after the first burn, with the almost complete failure of reproduction after repeated fires, is evidence that the sources of seed for the two stands could not be the same. The reproduction near the green timber in areas burned twice or more has evidently come in large part, or entirely, from seed trees, as indicated by the rapid decrease in the number of seedlings as the distance from seed trees increases.

TABLE 13.—*Average number of Douglas fir seedlings per acre after one forest fire in which all timber was killed*[1] *and on the same areas after they were reburned 10 to 15 years after first fire.*[2]

Distance from seed trees.	After one forest fire.	After reburning.	Distance from seed trees.	After one forest fire.	After reburning.
1 chain[3]	7,100	1,422	11 chains	3,920	9
2 chains	5,360	282	12 chains	3,000	0
3 chains	9,660	130	13 chains	4,175	9
4 chains	3,490	52	14 chains	770	8
5 chains	1,990	28	15 chains	195	8
6 chains	6,310	64	16 chains	400	7
7 chains	3,800	49	17 chains	500	0
8 chains	800	18	18 chains	6,850	0
9 chains	2,030	22	19 chains	8,820	6
10 chains	2,455	18	20 chains	4,840	3

[1] Examined 5 to 12 years after fire.

[2] Based on 172 square-rod plots examined annually for from 2 to 5 years, and on 3.75 miles of belt transect line examined from 1 to 5 years after the second fire. Areas at more than 20 chains from seed trees that had been reburned, of which previous records were taken, were not available. Plots were arranged in series running out from seed trees; consequently results from plots and transects could be averaged together.

[3] 1 chain equals 66 feet; 10 chains equals one-eighth mile.

YOUNG GROWTH FOLLOWING LOGGING.

DISTRIBUTION AND SPECIES IN UNBURNED SLASH.

Dense stands of young growth were found in unburned slash on areas where no seed trees were left. The young growth consisted largely of western red cedar and western hemlock and contained less of the other species that were in the stand before cutting. The vegetable matter and soil of the forest floor contain the seeds of all the species that form the stand, and those seeds germinate and form the new forest. In unburned slash the new forest usually contains a larger percentage of western red cedar and western hemlock, because more of the seed of these small-seeded species is near the surface.

On an area of unburned slash near Fairfax, Wash., where a mature stand of Douglas fir, noble fir, and western hemlock had been clear cut, permanent plots were established and were examined each year for five years. At the end of the five years there was a dense stand of reproduction, and the density did not vary in relation to the distance from the edge of the green timber. Some of the densest stands were 15 chains from green timber, and some of the poorer stands were within 2 chains of green timber. The age classes were evenly distributed throughout the area. (Pl. VII, fig. 1.)

The rate of germination after cutting and the density of the stand on this area are given in Table 14.

TABLE 14.—*Density of stand of seedlings and rate of germination in unburned slash near Fairfax, Wash.*[1]

Number of years after cutting.	Percentage of total germination each year.	Total number of seedlings per acre each year.
1	20	12,000
2	58	46,800
3	13	54,600
4	7	58,800
5	2	60,000

[1] The stand consisted of 7 per cent Douglas fir, 76 per cent western hemlock, and 17 per cent noble fir.

In the region near Hazel, Wash., the forest is approaching the ultimate cedar-hemlock type. The remaining Douglas firs are very scattered and consist of veterans about 450 years old among western red cedar and western hemlock. Although the soil is favorable for Douglas-fir reproduction, there is generally a relatively small percentage of Douglas fir in the young growth after cutting. This may be attributed to the scant seed from overmature Douglas fir trees that were in the stand before cutting and to the destruction of this seed by rodents. One area of unburned slash that was examined three years after logging where there were two to six western hemlock seed trees per acre, was covered with an average of about 12,000 seedlings per acre, 16 per cent of which were Douglas fir, 28 per cent cedar, and 56 per cent hemlock. The nearest western red cedar seed trees were at least 20 chains from the area, and there were no Douglas fir seed trees within one-half mile. Many of the western red cedar seedlings were found in clumps of five to seven individuals, which looked as if they had grown from buried cones. Such clumps occurred at such distances from seed trees that the cones could not have been borne on wind-broken twigs.

Another area in this region contained an average of nearly 10,000 seedlings to the acre, consisting of western red cedar, western hemlock, and Douglas fir from 1 to 4 years old. In this area there was no preponderance of western hemlock seedlings, although seed trees of this species were present, whereas the western red cedar seed trees were 10 chains and the Douglas fir 20 chains distant, respectively.

An area near Oso, Wash., contained from 15,000 to 20,000 seedlings per acre of western red cedar, western hemlock, and Douglas fir. There were one to three seed trees of western red cedar and western hemlock per acre. The neareast Douglas-fir seed trees were more than 10 chains distant. The larger percentage of germination occurred the first year after logging, germination continued for three years, and some western hemlock germinated the fourth year.

An area of unburned slash near Pacific Beach, Wash., 15 years after logging (Pl. VII, fig. 2), in a heavy forest of western red cedar, western hemlock, and spruce, with a few veteran Douglas firs, contained a good stand of reproduction consisting of 20 per cent Sitka spruce, 10 per cent Douglas fir, 50 per cent western hemlock, and 20 per cent western red cedar.

Unburned slash near Knappa, Oreg., 20 years after logging, contained a thicket of western red cedar, western hemlock, and Douglas fir, with the western red cedar and western hemlock predominating in numbers. In contrast to this, another area in the same locality, where the timber had been killed by the forest fire of September, 1918, was logged in 1919, and the slash left unburned. Two years later there was a dense cover of young growth, consisting of 85 per cent Douglas fir, 10 per cent hemlock, and 5 per cent spruce. There was no green timber within one-half mile of the area after the fire of 1918. This is an illustration of the change of forest type caused by fire. Had the fire of 1918 not occurred on this area, and had the slash been left unburned, the young growth would have been largely hemlock, but now it is almost a pure stand of Douglas fir. Young growth invariably follows cutting on areas where the slash is not burned, although the proportions of species may not be the most desirable. A summary of conditions found on areas where the slash was left unburned is given in Table 15.

TABLE 15.—*Average number of seedlings per acre in unburned slash 2 to 15 years after cutting.*[1]

Species.	Chains [2] distant from seed trees.									
	1	2	3	4	5	6	7	8	9	10
Douglas fir	180	60	75	172	310	215	10	305	510	18
Western red cedar	230	986	385	760	1,620	586	160	12,110	3,405	50
Western hemlock	1,460	10,720	3,680	3,140	5,600	2,615	3,805	35,680	7,680	205
Total	1,870	11,766	4,140	4,072	7,530	3,416	3,975	48,095	11,595	273

[1] Based on 3.8 acres examined by the plot and transect method.
[2] 1 chain equals 66 feet; 20 chains equal one-fourth mile.

TABLE 15.—*Average number of seedlings per acre in unburned slash 2 to 15 years after cutting*—Continued.

Species.	Chains distant from seed trees.									
	11	12	13	14	15	16	17	18	19	20
Douglas fir	172	65	155	78	150	35	48	115	210	800
Western red cedar	0	24	36	140	4,500	6,520	3,610	418	1,670	4,860
Western hemlock	1,410	1,280	3,120	12,980	24,320	1,460	3,120	4,200	6,120	8,650
Total	1,582	1,369	3,311	13,198	28,970	8,015	6,778	4,733	8,000	14,310

DISTRIBUTION AND SPECIES OF YOUNG GROWTH FOLLOWING SLASH FIRES.

The large amount of débris left after logging in the Pacific Northwest makes a very dangerous fire risk and necessitates burning the slash in order to protect the surrounding forests and property. This fire risk should be removed at the earliest opportunity. It is also necessary for good forest management that the slash be burned the first season after cutting. The great amount of slash left after cutting a mature Douglas fir forest makes broadcast burning the only practicable measure of disposal. When a broadcast slash fire runs over an area it may affect the succeeding young growth in different ways. It may burn the surface layer of litter and duff and leave conditions favorable for a good stand of young growth with Douglas fir predominating; or, all the duff may be consumed and a scattered stand of young growth result, except in very loose soil containing a good supply of seed; or, if the fire is hot enough to heat the mineral soil below the duff, a barren area may result.

The heating of the soil is the important point, and this can be controlled by selecting the time for slash burning. In the spring the soil and duff are wet and little heating occurs. The young growth following spring burning is evidence of the desirability of burning the slash in the spring.

An area in the Puget Sound region, which was logged in the fall of 1914, and on which there was a very severe slash fire in July, 1915, afforded an opportunity to study the effect of a late spring or summer slash fire. A series of plots, each a rod square, was established immediately after the fire, and annual examinations were made for five years. (Pl. VIII, fig. 1.) Very few seedlings followed after the July slash fire, except in the vicinity of green timber. All the seed on this area was destroyed by one fire, a possibility that must not be overlooked in determining the time of slash disposal. In the same region large areas of dense stands of young growth have followed slash fires that occurred in the early spring or late fall. (Pl. VIII, fig. 2; Pl. IX, fig. 1.)

The season of burning and the condition of the forest floor at the time of burning often determine whether or not young growth will follow a slash fire. On the area burned in July several small western red cedar and western hemlock trees were left standing, but they were all killed by the slash fire. The reproduction that followed consisted of a few scattered seedlings of western red cedar, western hemlock, and Douglas fir, generally in rotten wood or under logs. Some Douglas fir seeds had germinated under pieces of bark and had been able to force their way to the edge of the bark before the food stored in the seed was exhausted.

Some spring burns have been found where but little young growth followed the slash fire, and good stands have been found on areas burned in summer or fall; but the importance of spring burning is emphasized by the superiority of the average stands of young growth on these burns as compared with the young growth on the later burns. The average conditions of restocking are shown in Table 16. Fall burning may sometimes be done almost as safely as spring burning, but usually it is too wet to burn the slash after the forest floor has become wet enough in the fall to protect the seed.

TABLE 16.—*Average number of Douglas-fir seedlings per acre on areas burned over by slash fires, examined 2 to 5 years after fires.*[1]

	Chains[2] distant from seed trees.									
	1	2	3	4	5	6	7	8	9	10
Slash burned in spring first season after logging	690	485	1,125	4,120	570	160	218	565	2,714	12,905
Slash burned in summer first season after logging	310	165	415	65	50	0	0	45	15	0
Areas reburned after first slash fire	665	345	510	165	0	0	0	0	0	65

	Chains[2] distant from seed trees.									
	11	12	13	14	15	16	17	19	20	20
Slash burned in spring first season after logging	5,220	4,130	9,190	670	2,115	4,568	1,675	6,460	5,120	1,365
Slash burned in summer first season after logging	0	0	0	16	65	140	85	15	20	0
Areas reburned after first slash fire	0	0	110	35	0	0	0	0	0	0

[1] Based on 7.5 acres examined by plot and transect method. Early fall burns usually occur before the duff and soil are wet; consequently the effect is the same as that of summer burns. Both types are included in this summary.

[2] 1 chain equals 66 feet; 20 chains equals one-fourth mile.

On areas burned more than once it is possible that a few dormant seeds still remain. The endurance of such seeds may account for some fairly good stands at considerable distances from seed trees. Likewise, the distribution of seed by wind and birds, combined with favorable conditions for germination, may result in a scattered stand in some localities, but other areas with less favorable conditions remain barren. (Pl. IX, fig. 2.)

RESTOCKING BY SEED TREES.

On one area studied no seed trees of any species were left, except scattered Douglas-fir trees. The nearest stand of timber was about one-fourth mile distant. On this area, four years after the fire, an average of 3,680 seedlings per acre was found. Of these seedlings, 1 per cent was Douglas fir, 16 per cent grand fir, and 83 per cent western hemlock. The occurrence of the grand fir and hemlock seedlings can not be attributed to seed trees, and even the origin of the 1 per cent of Douglas fir seedlings is doubtful. Although the Douglas fir trees left on the area were known to have produced crops of seed, the entire crop was evidently destroyed by rodents. This same condition has been noted on other areas, and it often accounts for the establishment of the cedar and hemlock even among Douglas fir seed trees. The cedar and hemlock seeds are less sought after by rodents when Douglas fir seeds are available for food.

The influence of scattered seed trees of Douglas fir was found to be limited (Pl. X), although gradually seedlings get a foothold in the immediate vicinty of the trees, as shown by Table 17. Scattered seed trees evidently will not insure a complete stand for some time, and it is doubtful if the stand would be complete until the seedlings reach seeding age and restock the remainder of the area. Therefore, in this gradual process of seeding an area, protection should be given not only to scattered seed trees, but also to scattered young growth. (Pl. XI).

TABLE 17.—*Average number of Douglas fir seedlings per acre on areas burned two or three times, with scattered seed trees left.*[1]

Distant from seed trees.	Average number of seedlings per acre.	Distant from seed trees.	Average number of seedlings per acre.	Distant from seed trees.	Average number of seedlings per acre.
1 chain [2]	106	15 chains	0	29 chains	0
2 chains	208	16 chains	0	30 chains	0
3 chains	53	17 chains	0	31 chains	0
4 chains	60	18 chains	0	32 chains	0
5 chains	145	19 chains	0	33 chains	0
6 chains	0	20 chains	0	34 chains	0
7 chains	0	21 chains	22	35 chains	0
8 chains	0	22 chains	0	36 chains	0
9 chains	0	23 chains	24	37 chains	0
10 chains	80	24 chains	0	38 chains	16
11 chains	26	25 chains	0	39 chains	0
12 chains	0	26 chains	20	40 chains	0
13 chains	0	27 chains	0		
14 chains	0	28 chains	0		

[1] Based on 162-rod square plots examined annually for 5 years, and on 3.8 miles of belt transect line.
[2] 1 chain equals 66 feet; 40 chains equal one-half mile.

The foregoing facts brought out in regard to the origin of young growth in the Pacific Northwest lay the foundation for the methods required to keep the forest lands productive. They show also that present methods of slash disposal and fire control tend to devastate forest lands, and furthermore, that the methods now used can be made to conform to the requirements for securing young growth with practically no additional expense.

MIGRATION.

The preceding chapter emphasized the point that the greater part of the reproduction is due to seed that was within the burned or cut area before the fire or cutting and that other seed-distributing agencies are only incidental in restocking forest lands. However, denuded areas are slowly reclaimed through migration, and the species are changed within the forest through succession and competition. The effect of each of these factors on the composition and establishment of the Douglas fir forests is pointed out in the following discussions.

Migration of Douglas fir is a very slow process. On burned areas young growth appears in unexpected places; but, wherever it has been possible to get a complete history of the area, the explanation of such stands has usually been that there was some source of seed within the area and that some seed had remained viable in spite of fire. Large regions south of Tacoma, Wash., known as the Steilacoom Plains, have not been covered with forests for a long time, perhaps even centuries. The only apparent reason forests do not now cover this region is that young growth has been regularly destroyed by fire. The plains were probably frequently burned over by the Indians, or possibly the fires were caused by other agencies. That the forest was held back by some foreign agency is evident from the progress it is now making in taking possession of these plains. Where the forest is pushing its frontiers out into hitherto unoccupied regions an opportunity is afforded to study migration. (Pl. XII.)

These plains are, on the whole, somewhat unfavorable for forest growth, but some seedlings become established here and there within seeding distance of the forest. The belts of successively younger trees as the distance from seed-producing trees increases are conclusive evidence that the forest is moving out into the prairie by steps. Each belt, representing a forward movement of 3 to 5 and in some instances 10 chains, contains age classes from 1 to probably 20 or 25 years old. The advance seedlings beyond this strip are so rare that they can hardly be considered in the migration of the forest. It is evident that when these advance strips reach seeding age the forest is ready to advance another strip of about the same width. After trees become established the forest floor soon resembles that of a typical Douglas fir forest, and forest conditions are developed. Where forests of this type have reached maturity and have been cut or burned, the succeeding growth is the same as that elsewhere in the Douglas fir region.

This migrating type of forest is in such strong contrast with the stands of young growth generally found in the Douglas fir region of the Pacific Northwest that it is evident the seed from which the stand originated had a different source. The first forest that invaded this prairie region consists of a very uneven-aged stand containing trees from 1 to 40 years of age. The second forest following in the same region after the mature forest was destroyed is the typical even-aged young Douglas fir.

On areas that have been burned two or three times in other parts of the Douglas fir region, this same type of migration has been noted, but the variation in ages is not so distinct. Scattered seedlings of Douglas fir are frequently found at long distances from green timber. Sometimes clumps of young trees appear, and occasionally slopes are covered with good stands, although no other young growth is found in the vicinity. Such young stands or seedlings have been found to come from seed that had its source within the area. Sometimes, however, it is not possible to obtain a definite record of the conditions through the different fires. The definite migration in the prairie region also makes it seem unlikely that the young growth appearing here and there in large burned areas originated from seed that came from the green timber remaining around the edges of the burn.

Migration in the Steilacoom Plains is a clear demonstration of the progress of a Douglas fir forest when it is dependent upon seeding from adjacent timber. The aridity of these plains reduces the number of seedlings; but the proportion of age classes at different distances from the timber shows the rate of seeding, as conditions are equally unfavorable at these different distances. In localities where moisture and soil are more favorable, as in some sections of the Willamette Valley in Oregon, the forest makes more substantial progress through migration, because the percentage of seedlings established is greater. The distance covered by each seeding generation, however, is not greatly increased.

CHARACTER OF SECOND-GROWTH FORESTS.

Usually the same forest type that existed before the action of the disturbing or destroying agencies is reestablished. An immediate forest succession without the usual intermediate stages results either from dormant seed left after the removal of the previous forest or from other exceptionally favorable conditions for reseeding. Immediate succession is characteristic in burns in the Pacific Northwest. In successions of this character the forest which was removed by fire, cutting, or other agencies is replaced by the identical species of the original forest, although usually in different proportions. Wherever reproduction is found coming in after a fire which killed the entire forest, the dead trees and snags of the same species were also found.

The extensive, unbroken forests of Douglas fir in the Pacific Northwest have developed primarily through fires. If this region were left without fire for 600 or 700 years, the forest of Douglas fir would be greatly reduced in area, and the best Douglas-fir soils would be occupied by western red cedar and western hemlock. Without artificial interference, such as fire or logging, Douglas fir can not compete with western red cedar and western hemlock, whose ability to endure shade permits them to form an understory which crowds out the less shade-enduring Douglas fir. (Pls. XIII and XIV.)

If the Douglas fir trees mature or are killed by any agent other than fire, and the western red cedar and western hemlock remain uninjured, the openings made by the removal of the Douglas firs are immediately filled by the understory of western red cedar and western hemlock. For this reason a Douglas fir forest seldom maintains a pure stand after the first generation, and sometimes is entirely replaced at the end of the first generation. Stands of Douglas fir 50 years old with clear, straight boles and well-developed crowns sometimes have a complete understory of western red cedar and western hemlock of practically the same age. Although the Douglas fir may be 100 to 130 feet tall, the western red cedar and western hemlock understory is only 20 to 30 feet tall. But this understory is not suppressed beyond recovery; and as soon as the forest is opened the suppressed trees renew their growth and form the forest stand. Although there may be a number of veteran Douglas firs in a forest consisting mostly of western red cedar and western hemlock, there is no chance for the replacement of Douglas fir unless the entire forest is removed. On the other hand, it has been found that some stands which originally contained only about 5 per cent of Douglas fir have been succeeded after a fire by young growth which contained as high as 50 per cent.

If the enormous quantities of seed produced almost annually by the western red cedar and western hemlock had the same chances of succeeding as the Douglas fir, the entire forest would soon consist of these species. From the small seeds produced by the western

FIG. 1.—A dense stand of Douglas fir young growth on an area where the slash was burned in the spring the first season after cutting.

FIG. 2.—An excellent stand of young Douglas fir that followed one slash fire and was killed by a second slash fire. The second burn was 5 years old at the time the photograph was taken, and no young growth has replaced the stand that was killed.

Stand at left consists of pure Douglas fir that followed logging. The area at the right was reburned 12 years before the picture was taken. No young growth has followed on the reburned area, although there are Douglas fir seed trees in the background.

FIG. 1.—A young Douglas fir bearing seed at 14 years of age. Douglas fir has been found producing seed when 9 years old, and effective seed crops are produced at 20 years of age.

FIG. 2.—A scattered stand of Douglas fir seed trees left after logging. These have not been effective in restocking the area.

FIG. 1.—Old timber in the background: 4 to 30 years old in the middle distance; 1 to 10 years old in foreground. Seedlings are at maximum distance of 5 chains from mature timber and 2 chains from 30-year-old class.

FIG. 2.—Scattered stand of Douglas fir 12 to 25 years old—the stage before complete forest stand; 2 to 5 year old seedlings are coming in among the trees.

red cedar and western hemlock very shallow rooted seedlings spring up during the first season. This factor alone is very important in keeping these species from any but favorable, moist sites. Seedlings of these species must have two or three favorable seasons in order to become established sufficiently to insure them against drought.

COMPETITION.

In general, Douglas fir is not fastidious in choice of soil, if certain chemical and physical extremes are excepted, such as an abundance of common salt, lime, or water, and if it does not have too much competition. Under favorable conditions Douglas fir adapts itself to a variety of soils, and its occurrence depends more on the number and species of its competitors than on the quality of the soil. Douglas fir seedlings have a number of strong competitors, and usually the competing species have the advantage in endurance of shade or resistance to drought.[13] The common and most important competitors are listed in Table 18.

TABLE 18.—*Important species in the understory of the Douglas-fir forest.*

Scientific name.	Common name.	Region in which it forms a competing ground cover.[a]
Acer circinatum Pursh	Vine maple	1, 2, 3, 4, 5.
Acer glabrum Torr	Dwarf maple	1, 2, 3, 4, 5.
Acer macrophyllum Pursh	Broadleaf maple	1, 2, 3, 4, 5.
Alnus oregona Nutt	Red alder	1, 2, 3, 4, 5.
Apocynum androsaemifolium L	Dogbane	1, 2, 3, 4, 5.
Arctostaphylos manzanita Parry	Manzanita	5.
Arctostaphylos uva-ursi (L.) Spreng	Kinnikinnick	1, 2, 3, 4, 5.
Castanopsis chrysophylla (Dougl.) A.DC	Goldenleaf chinquapin	1, 3, 5.
Ceanothus cuneatus (Hook.) Nutt	Wedge-leaf ceanothus	1, 3, 5.
Ceanothus integerrimus Hook. & Arn	Bluebrush	1, 2, 3, 4, 5.
Ceanothus prostratus Benth	Mahala mats	1, 3, 4, 5.
Ceanothus sanguineus Pursh	Red ceanothus	1, 2, 3, 4, 5.
Ceanothus velutinus Dougl	Sticky ceanothus	1, 2, 3, 4, 5.
Chamaenerion angustifolium (L.) Scop	Fireweed	1, 2, 3, 4, 5.
Cornus nuttallii Aud	Western dogwood	1, 3.
Eriodictyon californicum (Hook. & Arn.) Torr	Yerba santa	3, 5.
Gaultheria shallon Pursh	Salal	1, 2, 3, 4, 5.
Hieracium albiflorum Hook	White hawkweed	1, 2, 3, 4, 5.
Linnaea americana Forbes	American twin-flower	1, 2, 3, 4, 5.
Myrica californica Cham	California bayberry	1, 2, 3, 4, 5.
Odostemon aquifolium (Pursh) Rydb	Tall Oregon grape	1, 2, 3, 4, 5.
Philadelphus gordonianus Lindl	Syringa	1, 3, 5.
Populus trichocarpa Hook	Black cottonwood	1, 2, 3, 4, 5.
Prunus emarginata (Dougl.) Walp	Wild cherry	1, 2, 3, 4, 5.
Pteridium aquilinum pubescens Underw	Western brake-fern	1, 2, 3, 4, 5.
Quercus breweri Engelm	Shin oak	3.
Quercus californica (Torr.) Coop	California black oak	3, 5.
Quercus chrysolepis Liebm	Canyon live oak	3, 5.
Quercus densiflora Hook. & Arn	Tanbark oak	3, 5.
Quercus garryana Dougl	Pacific post oak	1, 3, 5.
Quercus sadleriana R. Brown Campst	Sadler oak	3.
Rhododendron californicum Hook	California rhododendron	1, 2, 3, 4, 5.
Rubus parviflorus Nutt	Thimbleberry	1, 2, 3, 4, 5.
Rubus spectabilis Pursh	Salmonberry	1, 3, 5.
Salix spp	Willows	1, 2, 3, 4, 5.
Sambucus callicarpa Greene	Pacific redberry elder	1, 2, 3, 4, 5.
Sambucus glauca Nutt	Pale elder	1, 2, 3, 4, 5.
Symphoricarpos mollis Nutt	Snowberry	1, 2, 3, 4, 5.
Thuja plicata Don	Western red cedar	1, 2, 3, 4, 5.
Tsuga heterophylla (Raf.) Sargent	Western hemlock	1, 2, 3, 4, 5.
Umbellularia californica (Hook. & Arn.) Nutt	California laurel	3.
Vaccinium membranaceum Dougl	Thin-leaf huckleberry	1, 2, 3, 4, 5.
Vaccinium ovalifolium J. E. Smith	Tall huckleberry	1, 2, 3, 4, 5.
Vaccinium parvifolium J. E. Smith	Tall red huckleberry	1, 2, 3, 4, 5.

[a] See Figure 1. 1, western Washington; 2, western Oregon; 3, eastern Washington; 4, eastern Oregon; 5, southwestern Oregon.

[13] Hofmann, J. V. The Influence of Vegetation on Forest Tree Seedlings. Journal of Ecology, 1918.

This long list of shrubs, trees, and nonwoody plants that compete with the Douglas-fir seedlings emphasizes the need of getting a stand of young trees started immediately after the forest is removed. Nearly all these competitors can endure more shade than Douglas-fir seedlings and consequently are able to crowd them out when the rapid height growth of Douglas firs—their greatest advantage in competing with this ground cover—does not give them the lead.

The Douglas-fir forests of Oregon and Washington usually have an undergrowth of various species of herbs, shrubs, and trees ranging from sparse to dense. The density of the undergrowth varies inversely with the completeness of the stand of Douglas fir. (Pl. XV.) A dense stand of young growth of Douglas fir usually succeeds in crowding out all competitors. The competition with other species is more keen in open areas, and in some places Douglas fir is unable to compete successfully with other species and regains the area, if at all, only by a slow process of invasion.

In competition one species drives the other back, and the one that can best utilize the given combinations of soil, light, moisture, and temperature is the victor. Douglas fir often occupies the south exposures and the ridges, because it is better adapted to thrive in those localities than competing species. Where it does not occur on the deep, moist loam soils the competing western red cedar and western hemlock have prevented its establishment.

Where the Douglas-fir forests are delimited from the forests of western red cedar and western hemlock it is not because of the inability of Douglas fir to thrive at the boundaries between the types. In a favorable area the species makes no selection as to soil, but where conditions are less favorable it is forced by other species to occupy those soils to which it is better adapted. The Douglas-fir forests continue to crowd the western red cedar and western hemlock largely because of the ability of Douglas fir to establish its seedlings during their first season of growth. Its superiority in this respect over the western red cedar and western hemlock is due to its larger seed and the greater amount of food stored in the seed, which enables the seedling to send down a much deeper root system earlier in its life.

The seeding age of any species is also an important factor in competition. Nearly all the large areas of chaparral in southwestern Oregon are the result of repeated fires. Fires gradually reduced the number of seed trees, and although reproduction followed in the same manner as in the west coast Douglas-fir region, the succeeding fires often destroyed the forest before it reached seeding age.

The effect of the seeding age on the succeeding forest is clearly demonstrated in this region. There are large areas of almost pure knobcone pine in places that were formerly occupied by Douglas fir and its associated species. The chief reason the knobcone pine gained possession of the ground was its age of seed production. The knobcone pine produces a sufficient quantity of seed at 10 years of age to be a determining factor in the establishment of the type. The resistance of the cones to fire protects the seeds through the fire. For these reasons, if successive fires should occur at intervals of 10 or 15 years, the knobcone pine would stand a better chance of surviving than other species. If seedlings of any other species had become established on the area they would be destroyed by the next fire, and the species would be eliminated from the area before the next generation reached seed-producing age.

The lodgepole pine produces seed at a younger age than its associates, and its cones are persistent. In eastern Oregon the lodgepole pine holds the same relative position in succession that the knobcone pine holds in the southwestern part of Oregon. For these reasons lodgepole pine sometimes holds potential western yellow pine sites, or is a successful competitor with Douglas fir and the other north-slope species.

In some localities the brush has become so dense that it is almost a permanent type, although forest invasion, even under these conditions, still continues. Successive fires are of no assistance in re-establishing the forest on these brush areas. On the contrary, they are detrimental to the return of favorable conditions for forest growth. If the brush is left on an area the moisture conditions are improved, and the accumulation of litter increases the fertility of the soil and the moisture of the surface soil. Erosion, which is so general in this region because of the heavy showers, is retarded by a brush cover.

The summer drought prevents the establishment of forests on severe sites in the open; but seedlings are able to become established under the protection of the brush, and in this way, even though it is a slow one, the brush fields are essential to the natural establishment of forests. The brush is not suppressed by the forest until the trees are 30 to 40 years of age. The effect of the brush cover upon the improvement of soil conditions is shown in Table 19.

TABLE 19.—*Effect of fire on moisture and humus content of soil.*

Area No.	Date of latest burn on the area.	Aspect.	Percentage of moisture content.			Percentage of humus content.			Conditions of vegetation.[1]
			Surface.	6-inch depth.	1-foot depth.	Surface.	6-inch depth.	1-foot depth.	
1	1915	SE., 30 per cent.	0.25	5.4	4.1	2.1	4.9	3.6	Few sprouts; some annuals.
2	1915	SW., 30 per cent.	.3	2.75	3.95	2.7	3.8	3.4	Do.
3	1915	N., 10 per cent.	.87	3.0	4.5	[2] 4.6	2.0	3.4	Do.
4	1886	....do........	6.2	4.25	4.65	19.8	5.1	4.6	Heavy brush.
5	1914	SW., 40 per cent.	.75	5.65	6.9	5.2	5.2	5.6	Light brush.

[1] Areas examined in 1916.
[2] The brush on this area was killed by the fire of 1915 but was not consumed.

Table 19 also shows the direct relation between fires and the humus and moisture in the soil. The brush and young growth were killed in area 3, but not consumed by the fire, which showed that the fire was not so hot as on areas 1 and 2, where a clean burn occurred. The abatement of the fire on area 3 is reflected in the greater percentage of humus and a consequently greater percentage of soil moisture in the surface layers. The accumulation of humus due to the absence of fires and the accompanying increase of soil moisture are emphasized in area 4. The effect of two years of freedom from fires is shown in the increased humus and moisture in area 5. Sprouting from the roots causes a brush cover to form quickly after each fire in this region. Better moisture conditions are thus established by the brush cover, and invasion by forest-tree species is made possible.

The first general fires in this region occurred in 1854, soon after the mining rush of 1851. Since that time frequent fires have occurred, and some of the areas have been reburned a number of times. The most barren slopes, however, still have traces of a former forest. The young Douglas fir is gradually establishing itself under the protection of the brush and oak trees. Ninety-five per cent of the seedlings occur under single bushes or in areas of shrubby growth. The age classes represented in these brush areas indicate that the seed is being produced by the adjacent seed trees. The fact that practically no reproduction occures on the slopes beyond the influence of seed trees shows that all sources of seed within the area have been conpletely eliminated by repeated fires. The establishment of the seedlings in different positions in relation to seed trees is brought out in Table 20.

TABLE 20.—*The occurrence of Douglas-fir seedlings in relation to seed trees.*

Distance from seed trees.	Number of seedlings per square rod.	Age classes, years.
1½ chains[1] above seed trees on southwest slope	20	4 to 22
1 chain above seed trees on southwest slope	16	2 to 18
1 chain below seed trees on southwest slope	8	5 to 17
3 chains below seed trees on southwest slope	2	6 to 15

[1] 1 chain equals 66 feet.

GROWTH.[14]

RATE OF GROWTH IN YOUNG STANDS AND EFFECT OF DENSITY ON GROWTH.

The density of the stand of young growth not only affects its development during its early life, but it has an influence throughout the life of the trees and even upon their usefulness when cut.

Rate of growth is often the factor which determines the success of a species. The Douglas-fir seedling produces a more rapid height growth during its early life than does any of its associated species. The average height growth during the first few years may be small, as a result of early or late frosts which often cause a bushy form of seedling. When once the leader is formed, however, the height growth is very rapid.

The effect of the density of the stand on the height and diameter growth in young stands of Douglas fir is shown in Table 21.

[14] Growth figures are based on data gathered by E. J. Hanzlik, T. T. Munger, and the staff of the Wind River Forest Experiment Station.

TABLE 21.—*Effect of density of stand on height and diameter growth of young stands of Douglas fir in south central Washington.*[1]

Age in years.	Stands of less than 2,000 trees per acre.		Stands of more than 10,000 trees per acre.		Age in years.	Stands of less than 2,000 trees per acre.		Stands of more than 10,000 trees per acre.	
	Height.	Diameter at 1 foot above ground.	Height.	Diameter at 1 foot above ground.		Height.	Diameter at 1 foot above ground.	Height.	Diameter at 1 foot above ground.
	Feet.	*Inches.*	*Feet.*	*Inches.*		*Feet.*	*Inches.*	*Feet.*	*Inches.*
1	0.2	....	0.2	....	10	6.3	1.6	3.6	.8
2	.7	....	.7	....	11	7.7	1.7	4.2	.8
3	1.0	....	1.0	....	12	9.4	1.9	4.8	.9
4	1.4	0.2	1.3	0.2	13	11.8	2.2	5.5	1.0
5	1.9	.3	1.5	.3	14	14.2	2.3	6.3	1.1
6	2.5	.5	1.8	.4	15	16.9	2.5	7.2	1.2
7	3.2	.7	2.2	.5	16	19.4	2.7	8.9	1.3
8	4.0	1.0	2.6	.6	17	22.1	2.8	10.3	1.4
9	5.0	1.3	3.0	.7	18	24.7	3.0	12.4	1.5

[1] Read from curves based on measurements of 16.75 acres.

Young Douglas fir in dense stands is definitely retarded in growth, but it does not stagnate. There are always a number of dominant trees, and the natural thinning is rapid during the first two or three decades. During the period before the stand reaches merchantable size, too great density can be remedied only by artificial thinning, and this involves considerable expense. Stands may start as dense as 50,000 or 60,000 seedlings to the acre, but at the age of 20 years they would be reduced to probably not over 20,000. The average stands, however, are not so dense. They may contain from 2,000 to 10,000 seedlings to the acre during the first 15 years, and at 25 years of age they may not contain more than 2,000 trees. After the age of 20 years the thinning continues rapidly. At 35 years of age the average acre of Douglas fir forest contains only about 500 trees. This number is reduced to about 250 at the age of 50 to 60 years, and 75 to 100 trees to the acre at the age of 100 years. Many overmature forests that are now being logged contain from 20 to 50 trees to the acre.

Growth in a scattered stand would be more rapid during the early stages, but the lateral branches would grow to larger size and be persistent on the trees. These branches cause the knots that are often found in large Douglas-fir trees that have apparently clear boles. In the dense stands of young growth the lateral branches are small. They die in a few years, and after they fall the trunk remains clean throughout the life of the tree and produces clear lumber. It is important, therefore, that the stand be started with at least sufficient density to insure clearing of the trunk in the early life of the tree. For this reason it is desirable that there be at least 800 trees to the acre, and even a much greater density is not a serious hindrance to the development of the young trees.

The process of natural thinning results in the loss of a large amount of the material grown on an area. If artificial thinning were employed, this material could be utilized at different stages throughout the life of the forest. The thinnings would improve the quality of the remaining trees and increase the rapidity of growth. The dense young stands that spring up naturally after logging could be utilized at 25 years of age for pulp wood. At that age little heartwood has been formed, and a harvest of about 2,500 cubic feet to the acre could be obtained from good stands. At 35 years of age stands of this character would yield up to 2,000 posts to the acre, and at 45 years of age there would be 350 to 400 trees to the acre suitable for ties. At 55 years the stand would average about 110 feet in height and would be suitable for poles and piles. On favorable sites Douglas fir may yield 40,000 board feet to the acre at 60 years of age. Stands of 100 to 200 years make an annual growth of 500 to 1,000 board feet to the acre. This excellent growth diminishes little until the trees have reached the age of about 200 years, but from that time on it is much less. At about 250 years the timber begins to show the effects of decay. After this age growth in the forest may not be greater than the loss resulting from the death of trees from disease or other causes.

The best growth occurs on the gentle, well-drained slopes and benches at the lower altitudes west of the Cascades and in the Coast Mountains. In middle age the more densely stocked stands occur on the south or exposed slopes, and the least dense on the cool north slopes. Humidity is an important factor in promoting this phenomenal growth. Consequently, the best growth occurs in the coast regions, where fogs are comparatively common.

SILVICULTURAL MANAGEMENT.

MATURE AND OVERMATURE FORESTS.

The present merchantable forest of Douglas fir generally consists of a mature or overmature stand. (Pl. XVI.) Management in these forests for the purpose of securing a second crop and protecting the existing young stands requires proper methods of cutting, slash disposal, and fire protection.

METHODS OF CUTTING.

Clear cutting is the most feasible method with the present system of logging, and it also produces the best results from a silvicultural standpoint. All trees and snags that are large enough to remain standing through a slash fire should be cut whether they are merchantable or not, unless they are to be left as seed trees. A diameter limit is not a satisfactory basis for classifying the material to be felled, because such a limit would have to be different in different places or even within the same area. The important thing is to get all the material on the ground before the slash fire. Trees up to about 12 inches in diameter at breast height are usually torn down by the cables in the areas through which a large number of logs are skidded. On the outside of the settings, however, the logs are pulled out in more direct lines, and a large percentage of small trees remain standing after the logging is completed. This is the principal reason why a diameter limit would not solve the problem satisfactorily. Material left standing after all operations are completed should be felled before the slash is burned. If trees and snags are left after the slash fire, they form a fire hazard for the entire area and add to the cost of fire protection. Standing trees are generally killed by slash fires and begin falling a few years later. This creates a fire hazard among the young growth that may have followed after the first slash burn. The reburning of the area in order to remove this débris is dangerous, because the second fire on an area is likely to prevent restocking.

The overmature stands of Douglas fir in which western hemlock, silver fir, noble fir, grand fir, and other species are mixed sometimes produce a low percentage of material that is merchantable with the present methods of utilization. Therefore much unmerchantable material remains standing, and it is not possible to leave the area in suitable condition for restocking. It would be better forestry to postpone the cutting of areas of this type until trade practices and close utilization make it feasible to cut and use all the species.

SEED TREES.

On some areas a large volume of Douglas fir remains that is unmerchantable because disease has made it defective. Unmerchantable Douglas-fir trees should be left standing to serve as seed trees to assist in restocking the area and as a source of seed in case a second fire should occur. There are scarcely any logging areas on which there are enough unmerchantable Douglas-fir trees to interfere with restocking if they are left standing. About two seed trees per acre should be left. Although some Douglas-fir trees are windthrown when left standing singly, loss from this cause is not common. If only large merchantable trees are available, the leaving of seed trees may be prohibitive from a financial standpoint.

SLASH DISPOSAL.

Mature or overmature forests produce the conditions that are generally favorable to the coming in of young growth after a forest fire. The litter and duff form a deep layer on the forest floor, and the cool, shady situation under the forest provides favorable conditions for seed storage. When this type of stand is cut, the leaving of a large amount of débris after logging is inevitable. Piling the slash can not be considered, because there is too much heavy material left on the ground and too much débris to be piled. To remove the fire hazard thus created necessitates broadcast burning. This method will probably be continued for some time in these virgin stands of Douglas fir and associated species. New ways of utilization may cause some variation in the methods of logging and slash disposal, but there is no system of cutting now in use that will appreciably reduce the amount of the débris.

Not only does a broadcast slash fire create an intense heat and endanger both the seed in the forest floor and the seed trees themselves, but it is also a menace to surrounding stands of timber or young growth. Consequently it is desirable to reduce the heat as much as possible and prevent the spreading of the fire beyond the area of slash to be burned. The method best adapted for securing these results is summed up in the following rules:

1. Burn the slash the first season after logging.
2. Burn the slash in early spring or late fall when the forest floor is moist.

3. Set the fire on a still evening, usually after sundown.
4. Burn away from the edge toward the center all around the area to be burned and from the base of all green trees to be left. On steep slopes burning should begin along the top edge and be carried down through the slash by parallel strips along the slope.
5. Protect all adjacent young growth. If necessary, put fire lines along the edge of a young stand on slopes or where there is dry material among the young growth.
6. Before burning the slash, cut all snags and unmerchantable trees, except trees to be left for seed, in order that as much débris as possible may be consumed in the first fire.
7. Construct fire lines between old burns and new slash where it is necessary in order to prevent the fire from running back over the old burns.
8. After the slash is once burned, keep out fire until the new stand is matured and logged.

The application of these rules in handling mature and overmature Douglas fir forests is the best preparation for future forests.

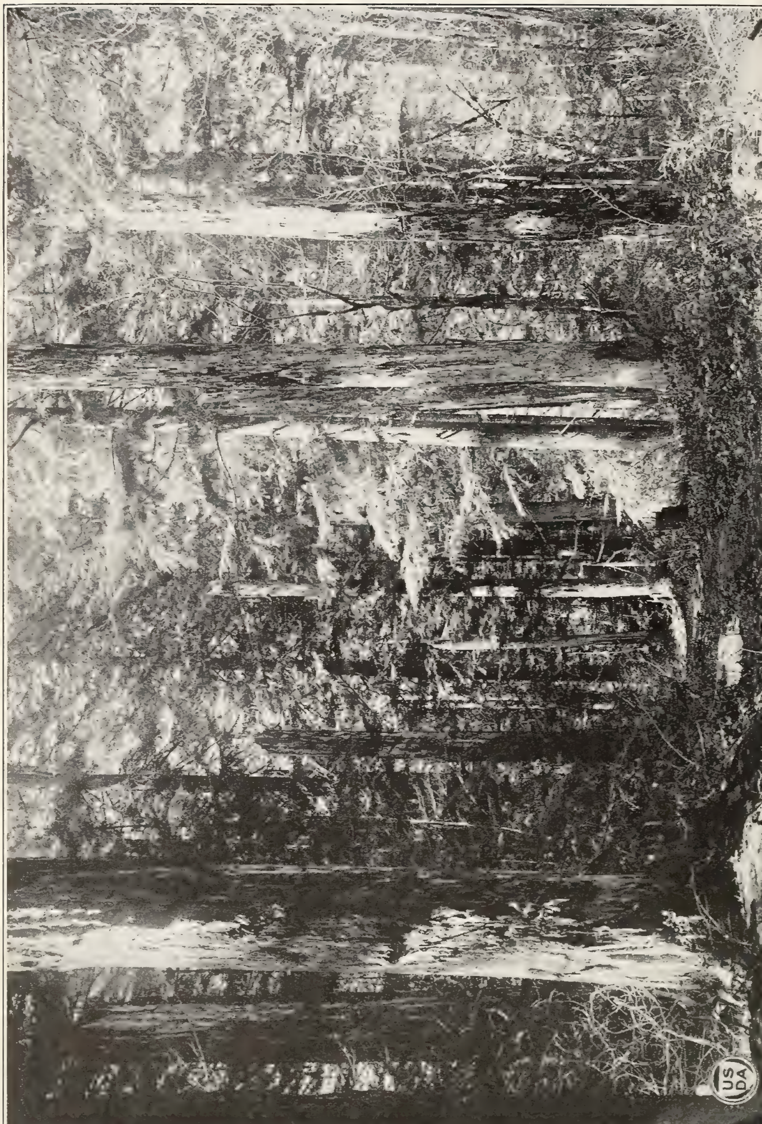
There is a definite reason for burning the slash in the night and while there is no wind. Usually the night air contains more moisture, which prevents the fire from burning so briskly as in the daytime, so that the green timber at the edge of the slash and the green trees left on the area are protected. A slash fire during a hot, dry day invariably kills all standing trees and, moreover, is apt to start a crown fire in adjacent timber.

Crown fires will travel in clean young Douglas-fir stands only before a high wind or on steep slopes, and will scarcely ever travel at night. Consequently a stand of young growth at the edge of the slash is fairly well protected if the burning is done at night. The trees left after logging are generally not killed by overheating of the base or trunk, but the needles are either dried or burned by the heated air or flame rising through the crowns. If the bark is unbroken and there are no pitch pockets on the trunk, a mature Douglas fir will withstand the heat of a slash fire. Experiments have shown that bark 4 inches thick on a mature Douglas fir resisted, without injury to the growing tissue inside, a heat of 900° F. applied for 4 hours; and that slash fires heated the trunks from 800° F. to 1,400° F. for periods of 5 to 20 minutes without harm. Trees 35 years old with bark 1½ inches thick were killed after 52 minutes, and 15-year old trees with bark one-fourth inch thick were killed after 11 minutes in a heat of 900° F. Young trees 8 years old with bark 0.15 inch thick were killed in 1 minute and 10 seconds. These figures show why it is important to keep all fires away from young stands and why older trees live through hot fires, provided the flames do not reach the crowns.

The needles will not burn unless a great deal of water is evaporated from them, and so it is important to prevent the generation of sufficient heat to dry them. If fire is set at the edge of a stand of young growth it burns away from the young stand, and the heat developed is not so intense as that of a fire that runs up to the stand and that may destroy the young growth for some distance at least, and even pass through it.

FIG. 1.—Stand of western red cedar and western hemlock, replacing Douglas fir, during the first generation. Dead Douglas fir snags appear in the center.

FIG. 2.—An almost pure stand of Douglas fir 50 years old; western hemlock and western red cedar in the understory. On this area the Douglas fir forest will be almost completely replaced by western red cedar and western hemlock at the end of the first generation if it is left undisturbed.



An overmature forest of Douglas fir in the Wind River Valley, southern Washington. All Douglas fir trees are dead, and are being replaced by western hemlock.

Douglas fir young growth in competition with vine maple, bracken fern, alder, and other species. Douglas fir seedlings grown in deep shade make rapid height growth but little diameter growth; if they survive until they overtop the brush, they soon take possession of the area.

An overmature stand of Douglas fir; western hemlock understory. The trees are 3 to 5 feet in diameter breasthigh, about 225 feet high, and 450 years old. Wind River Valley, southern Washington.

If the slash is burned broadcast immediately after logging and thereafter good fire protection is provided, land in the Douglas-fir region is generally restocked soon after cutting. Some of the cut-over areas have been utilized for agriculture or pasture. About 40 per cent of the remainder, however, is now restocked with good young stands of Douglas fir, although restocking was unintentional. The more or less dense stands that follow after this method of cutting are desirable because they produce the best form of trees both in the young stands and in the older forests.

Provided the fire risk were not too great to make it safe to leave slash unburned, this method would result in a preponderance of western red cedar and western hemlock in the young stands where these species make up an appreciable proportion of the forest before cutting.

Nature has provided means for the perpetuation of the Douglas-fir forest, and it is fortunate that the methods of logging employed need not be materially changed to permit natural restocking. System is essential, however, in methods of cutting and slash disposal. Burning slash at the time when the area will be left in the best condition for natural restocking is the best safeguard. If the slash is disposed of immediately after logging, a fire risk that endangers the logging camps and equipment is removed, and spring or late fall burning gives the greatest insurance against the spread of the fire to areas that are not ready to be fired or to which damage would be done. Spring fires are not dangerous to surrounding timber or clean young stands, but they must be kept away from open areas of older burns and from areas of young growth that contain inflammable débris.

The danger that a spring fire will last into the summer and be a constant source of risk can be avoided by the judicious burning of the slash and by the care of the fire after the main burn. The area should be patroled and all fire completely extinguished.

THE FOREST GROWN UNDER MANAGEMENT.

After the virgin mature stand has been replaced by second growth the cutting cycle may be between 80 and 120 years, a period that will produce entirely different silvicultural conditions. In some of the young stands, even those 50 to 60 years old, logging is now being carried on in a few localities. Many of these young stands of Douglas fir are almost pure. The tops and the lateral branches are small and are usually broken during logging. With clear cutting in this type of forest it is feasible to pile the brush and burn it when the fire will not spread over the surface of the ground between the piles. If the brush is burned in piles and the remainder of the area is left unburned, the seed already in the forest floor will be saved, and young growth will be insured without seed trees. The method to be employed for securing reproduction after cutting, therefore, divides the Douglas-fir forest into two distinct classes—one, the overmature or mature forest, in which there should be broadcast burning of slash, the other, the younger managed forest, in which the brush should be piled and burned.

ENEMIES.

FIRE.

The fire situation in the Douglas-fir region of the Pacific Northwest complicates for the timber owner and the forester the problems of nonproductive land and the preservation of existing merchantable timber and young growth.

FIRE RISKS.

Effective fire protection requires a classification of the areas on the basis of comparative risks. In order to classify the degrees of fire risk, it is necessary to analyze each type of forest and the relation of each type to all other types, so as to recognize clearly the areas that present the greatest risk and all the gradations of risk down to the least.[15] As in fire insurance the extremely hazardous risks pay a higher rate of insurance than safer ones, so must the extremely hazardous forest area receive more fire protection than the less hazardous. Classification of risks in fire insurance is based on the occurrence of fires in certain types of construction, on exposure, and on kind and degree of protection. The forest-fire risk depends upon the composition of the forest, the exposure, the inflammability, and the degree of protection given by the owner, the operator, or public agencies. Because of the fires that have actually occurred some areas would be classified as extreme risks, but many of these fires may have been due to lack of protection or to other controllable conditions.

Inflammability is a standard that can be used as a basis for determining degree of risk. All other factors entering into the degree of risk vary locally and must be considered in connection with each area. With respect to inflammability the Douglas-fir forest region may be divided as follows according to the comparative degree of risk, the greatest risk being put first:

1. Unburned slash.
2. Open burned area, with dead weeds and some dry brush or branches.
3. Young stand up to 20 years old, with dead material on the ground and with standing snags.
4. Open stands of young growth, with weeds and grass beneath.
5. Overmature stands, with a number of snags and down logs.
6. Overmature stands, with few or no snags.
7. Dense young stands, 10,000 to 20,000 trees to the acre, 10 years to 30 years old, with clean floor.
8. Well-stocked young stands, 3,000 to 10,000 trees to the acre, 10 years to 30 years old, with clean floor.
9. Merchantable stands, 30 years old and older, with clear boles and clean floor.

Unburned slash is no more inflammable than an open area with dry grass or weeds; but it is a more dangerous risk because it develops an uncontrollable fire with intense heat and strong drafts, and also makes a longer fire season. Unburned slash is a continuous

[15] Hofmann, J. V. A Forest Saved is a Forest Grown. West Coast Lumberman, vol. 39, No. 465, Feb. 15, 1921.

risk from early spring to late fall, but in the open area the danger period is confined to a time in the spring before the new vegetation covers the ground and to a period in the fall after the vegetation has dried up or has been killed by frost.

The inflammability of any material is in direct relation to the amount of moisture it contains, and the amount of moisture in the material is largely regulated by the condition of the air. Evaporation depends primarily upon the relative humidity of the air. Wind velocity, temperature, vapor pressure, and barometric pressure are influencing but secondary factors.

The fire risk may be about equal in a young Douglas-fir stand with snags and débris and in an open stand with dry grass or weeds, so far as starting a fire is concerned, although the rate of spread and difficulty of control make the former a much greater hazard. The snags and débris not only spread the fire rapidly, but also develop such a high degree of heat that all the young growth is quickly killed and dried to the point of inflammability. The snags also form a dangerous risk throughout the season. In an open Douglas-fir stand a fire will spread rapidly if fanned by a wind, but the surrounding air is not heated so much, and consequently only a part of the young growth is killed and little of it is burned. The season of high risk is shorter, because it is confined to the periods when the grass and weeds are dry. Some of the overmature Douglas fir stands contain a large percentage of dead and decaying trees, which are a detriment to the stand from a commercial standpoint and in addition make a dangerous fire hazard. During the dry season snags are easily ignited and burn so furiously that they spread fire rapidly and cause the flames to climb into the crowns of nearby trees. In a mature stand free of snags a crown fire is not so likely to develop from a surface fire as in a stand containing snags, and the fire is easier to control because it is on the surface only.

The needles, being the most inflammable, constitute the principal fuel for the spread of a crown fire. Douglas fir needles will ignite when they contain moisture equal to about 35 per cent of their dry weight. Consequently, any amount of moisture greater than 35 per cent must be evaporated before the needles will burn. They ignite at a temperature of about 650° F. and burn quickly.

The water content of Douglas fir needles varies greatly through the season and is, no doubt, the underlying factor in the behavior of crown fires in mature forests and in the spread of fire in young stands. During the season of 1921 the percentage of water content of needles in mature Douglas fir was as follows: 95.9 per cent in early May, 77.3 per cent in early July, and 100.4 per cent in late September. Coincidently, the respective percentages of water content of the needles of well-stocked young growth 13 years old were 120.8, 99.0, and 115.3. This means that a fire, in order to burn Douglas fir needles and to spread, must evaporate the following amounts of water, based on the dry weight of the needles:

	Early May.	Early July.	Late September.
	Per cent.	*Per cent.*	*Per cent.*
In mature timber	60.9	42.3	65.4
In young growth	85.8	64.0	80.3

From these figures it is readily seen that a crown fire will spread most rapidly in summer in either mature timber or young growth, and that young growth in this respect is not so great a fire hazard as mature timber. Young growth, during the driest season, is not as inflammable as the mature timber in the spring.

The fire danger in a clean mature forest as compared with that in a young stand of Douglas fir depends upon the inflammability of the needles, which in turn is in direct relation to the amount of water contained in them. A green stand of young or mature Douglas fir will not burn until the needles are dried to the point of inflammability. The rate at which the needles are dried determines the rate of spread of the fire, and when the heat ahead of the fire is not intense enough to dry the needles a crown fire stops. For the same reason a crown fire will start only where there is enough inflammable débris beneath the stand to heat the air and dry the needles before it. For these reasons a slash area adjacent to a green stand either of young growth or mature timber always constitutes a dangerous risk. (Pl. XVII.)

Experiments show that in a mature stand of Douglas fir with 32 trees to the acre, 1,500 gallons of water per acre are evaporated from the needles before the inflammability point is reached; in a stand of young growth 12 years old with 20,000 trees per acre, 2,300 gallons per acre are evaporated; and in a stand 12 years old containing 8,000 trees per acre, 3,900 gallons per acre are evaporated. Of the two types of young stands the well stocked are less inflammable than the very densely stocked. The difference in water content of the needles in different stands is due to the rate of growth of the tree and the proportion of new needles to old. Mature stands grow very slowly and retain the needles in whole or in part for 6 or 7 years, with the result that the proportion of new needles to the older ones is small. Older needles contain more resinous deposits and mineral matter and less moisture than new ones and are, therefore, more inflammable. In a dense young stand the top shoots grow rapidly, but the side branches are crowded and make little growth. This leaves a high proportion of new needles, but the total needle growth is less than in a young stand in which each tree has growing space enough to allow all of the side branches to develop new needles. Dead twigs on the stems are very inflammable and will carry a fire through a dense young stand which would not burn if only green twigs and needles were present.

Clean, well-stocked young stands are the lowest fire risk. The degree of hazard in these stands depends upon the density of the stand; the denser the stand the greater the inflammability. It is an encouraging fact in the management of Douglas fir that the most desirable forest—the well-stocked young stand—is at the same time the lowest fire risk.

FIRE PROTECTION.

The greatest factor in forest protection is the prevention of fire. An analysis of the fire risks is the greatest aid in prevention, because it makes possible the most effective use of the protective force. Fire protection may be effectively accomplished through the efforts of individual owners, although it almost invariably proves to be expensive. At present a large degree of protection is afforded in the

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A slash fire has been stopped by dense green Douglas fir reproduction. The fire killed only a narrow fringe of trees 75 to 100 feet wide along the outer edge of the main stand.

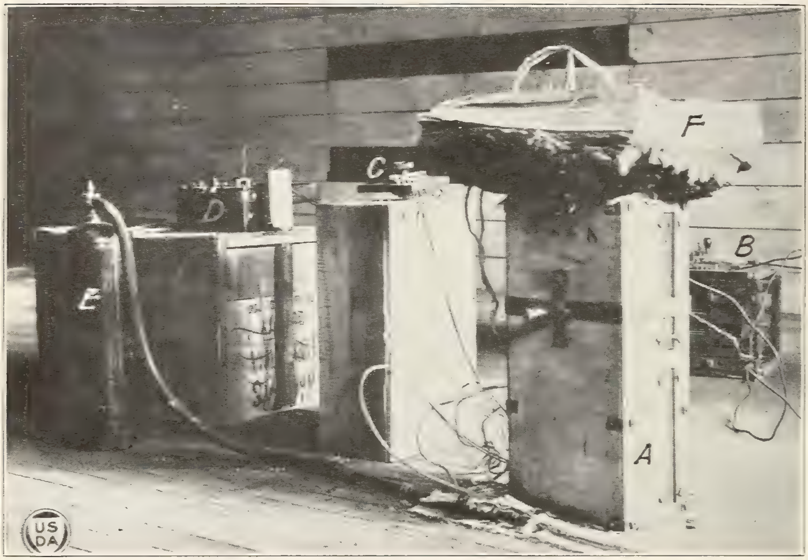

FIG. 1.—Apparatus used in controlled temperature tests, showing block in position for testing the heat resistance of Douglas fir bark. *A*, heating apparatus; *B*, rheostat; *C*, switch; *D*, potentiometer; *E*, presto tank; *F*, block of green Douglas fir with thermocouples inserted to cambium ring.

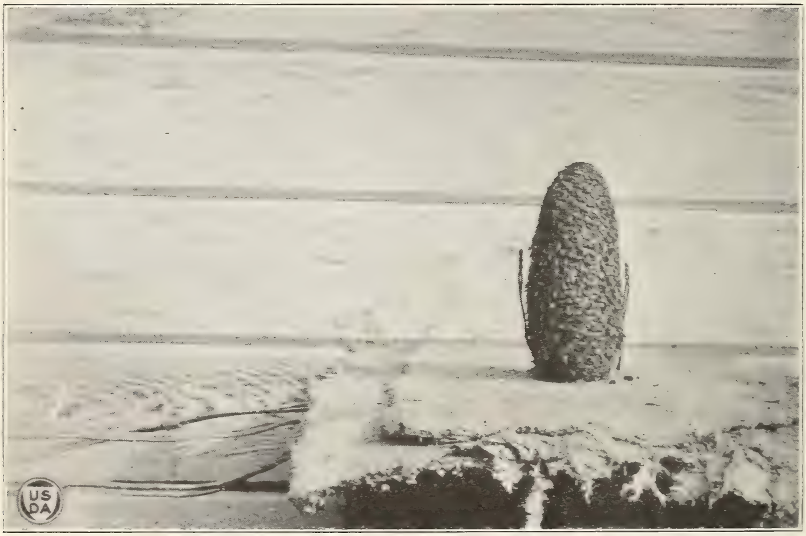

FIG. 2.—Cone of noble fir prepared for insertion into heating apparatus. On both sides are shown thermocouples for recording the heat applied. There is also a thermocouple in the center of the cone for recording inside temperature.

FIG. 1.—Flowers of Douglas fir. *A*, staminate flowers borne back from the tips of the branches; *B*, pistillate flowers, borne next to the terminal buds. Flowers open before the leaf buds.

FIG. 2.—Cones of Douglas fir. The cones are borne on the wood of the last season. Each of the trident, protruding bracts has a long central point.

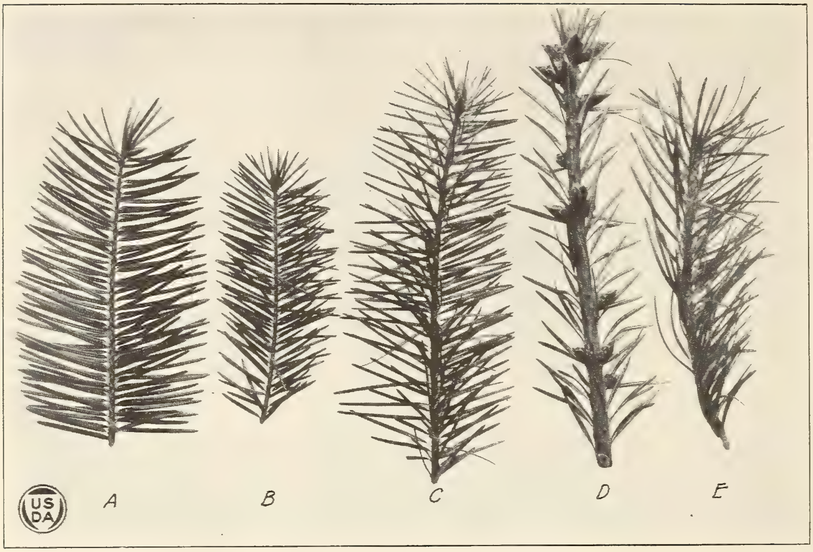

FIG. 1.—Leaves of Douglas fir. *A*, two-ranked arrangement usually in shade; *B*, small shade form of leaf; *C*, open grown with leaves distributed around branch; *D*, leading shoot, with flat, pointed leaves; *E*, twig of old tree, with leaves turned up and appearing to be on top of branch.

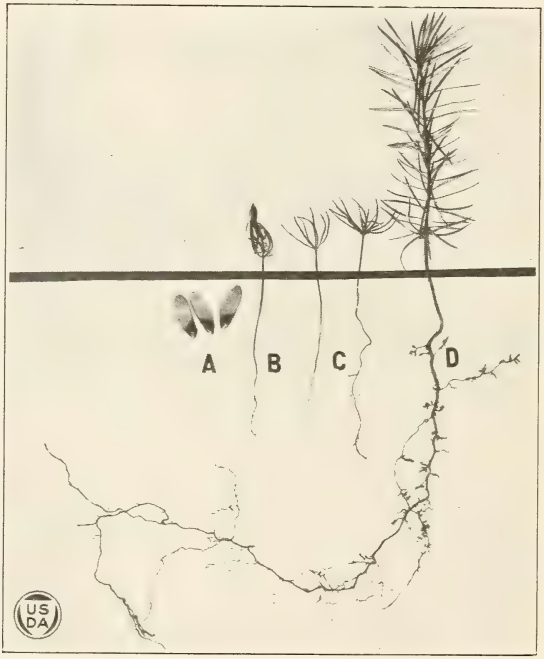

FIG. 2.—Douglas fir seeds and seedlings. *A*, seeds with wings as they come out of the cone (there are on the average about 38,000 seeds to 1 pound); *B* and *C*, seedlings as they appear above the ground, up to 2 weeks old; *D*, seedling 1 year old, 3¼ inches high, with a good root system. The root penetrates deeply and enables the seedling to live on drier slopes than do the shallow-rooted seedlings of western red cedar and western hemlock.

Douglas-fir region by collective effort through an assessment plan. The annual cost averages about 2½ cents per acre. The need for adequate protection from fire is urgent in the various stages of the Douglas-fir forest from its beginning to its maturity.

DISEASES.

Fortunately no diseases have been found that threaten the Douglas-fir forest. The only serious attacks occur in the young seedlings and in the overmature trees.

From the time the seed swells before germination until the seedling has formed woody tissue at the age of 30 to 40 days, losses are caused by the damping-off fungi, and these losses sometimes become serious. After the seedling is established the Douglas fir is essentially free from disease until it has reached the age of about 150 years. In the overmature forest it is seriously attacked. As the forest under management will be cut between 80 and 120 years of age, it promises to be practically free from disease.

The rots in the present overmature forests, however, have a direct bearing on the future crop. Trees that have been attacked seriously enough to render them unmerchantable may be left standing to serve as seed trees. It has been shown that such trees produce less seed, but that the quality is apparently as good as that of the seed from sound trees. The rots that cause the most damage are the ring-scale fungus (*Trametes pini*), the velvet-top fungus (*Polyporus schweinitzii*), the quinine fungus (*Fomes laricis*), and the rose-colored fomes (*Fomes roseus*).[16]

INSECTS.

In comparison with some other important forest trees in Oregon and Washington, Douglas fir ordinarily suffers but little from tree-killing insects. Probably the most important Douglas-fir insect in the region is the Douglas-fir beetle (*Dendroctonus pseudotsuga* Hopk.), which kills Douglas fir by mining out the inner bark. Losses caused by this insect are far more frequent in the border type than in the Douglas-fir region proper.

The felling and barking of the infested trees beginning with the first of November and ending with the first of the following March will be sufficient to kill the broods. The barking of newly infested trees during July and the first half of August is also permissible in the case of this species and sometimes desirable because this is the period in which the principal larval development takes place and before the broods of adults have matured sufficiently to fly when liberated from the bark.

The fact that the species is attracted to the living bark on trunks and stumps of recently felled trees suggests the efficiency of the trapping method of control.

Continued cutting operations within a given locality, especially in the coast region, usually serve to protect the living timber from attack by this beetle.

In case areas are found infested by this or other bark beetles, the Bureau of Entomology should be consulted for advice as to the method of control most suitable in the given locality.

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[16] Boyce, J. S. Decay in Douglas Fir. The Timberman, Vol. XXIII, No. 1, Nov., 1921.

The Douglas fir bark weevil (*Pissodes fasciatus* Lec.) attacks medium to large saplings of Douglas fir and kills them by boring beneath the bark toward the base and along the stem. In controlling bark weevils reliance must be placed on systems of forest management which will bring about conditions unfavorable to them.

Occasionally, in the Douglas fir forests of the Oregon and Washington coast, extensive defoliations by caterpillars occur.

The spruce budworm (*Harmologa fumiferana* Clem.) has been found to defoliate Douglas fir seriously in Idaho and there are indications that ravages by this important pest are increasing throughout Idaho and elsewhere. Any records of serious defoliation of Douglas fir should be reported to the Bureau of Entomology, and specimens of the insects or their work should be submitted also. This insect and other defoliators can only be controlled by a system of forest management which will decrease the species most favorable to the insect in the forest types concerned.

Defoliations by needle-devouring insects during the past 30 years on thousands of acres in the Grays Harbor portion of southwestern Washington, and in Clatsop and Tillamook Counties of northwestern Oregon, have resulted in the loss of many millions of feet of timber. Often both Douglas fir and western hemlock are defoliated by the same insect. In 1919 and 1920, the western hemlock looper (*Therina Ellopia somniaria* Hulst), killed at least 400,000,000 board feet of high-quality Douglas fir and western hemlock in Tillamook county, Oreg. The dead trees scattered through this damaged area are now a serious fire risk, and if they should burn they would not only kill much of the timber that was left unscathed by the defoliators but would also destroy the young growth which follows in such insect-killed areas. Unfortunately, however, no control measures against these defoliators seem now to be practicable.

SUMMARY.

The future of the lumber industry in the Pacific Northwest depends on perpetuating the forest, an objective for which Douglas fir is peculiarly fitted because of its remarkable ability to restock, its rapid growth, and its high yield.

The Douglas fir is well adapted to the climate and soil of the Cascade region and the western sections of Oregon and Washington, and produces good timber in the dry regions as well as in the areas of greatest precipitation, and on all exposures from sea level to elevations of 3,500 to 4,500 feet.

Restocking of Douglas fir occurs naturally in the Pacific Northwest if the forest is properly handled. As young growth comes chiefly from seed stored in the forest floor, it is necessary to protect this seed during logging and burning.

The vitality of the seed and the activity of rodents in burying seed are the principal factors that insure a supply of seed in the forest floor at all times.

Seed in cones on the trees will live through a forest fire. Protected by a cover of mineral soil or of moist litter and duff, seed survives forest or slash fires. Dense stands of young growth originate from seed that has passed through a forest fire or a slash fire, or sometimes a combination of the two.

Distribution of seed by the wind is limited for effective restocking to a distance of 5 chains from green timber, although occasionally seeds may be carried farther. The limited distance to which seed is distributed makes migration of the forest slow, usually only a few chains during each seeding generation.

Clear cutting is the method now used in logging and it should continue to be used. All trees should be cut except those that are to be left as seed trees. If seed trees are depended upon for restocking, approximately two trees per acre should be left.

Slash should be burned after logging in order to obtain the best conditions for natural restocking. Areas must not be reburned.

Spring burning of slash leaves the area in the best condition for natural restocking. This method can be practiced successfully if the slash fire is properly handled. After the slash has burned, all smoldering fires must be put out.

Fire protection is essential to keep the land in continuous production, and its cost is the only one involved in the restocking of Douglas fir in addition to the cost of proper cutting and slash disposal.

Where stands of young growth are destroyed by fire before they have reached seeding age, restocking depends upon seed produced by trees of seeding age. If these trees are not available, such burns result in barren areas that are reclaimed by forest migration only after several successive generations of seed trees.

Douglas fir usually does not successfully compete with its associates without the aid of its ally, fire. If fire is kept out of the Douglas fir forests for several generations, such associated species as western hemlock and western red cedar in some localities will form the understory and replace Douglas fir. Moreover, this change of type sometimes develops during the first generation; but ordinarily, following a single fire in a mature forest, or after a proper burning of slash, restocking to Douglas fir occurs immediately from seed that was stored in the duff before the fire.

APPENDIX A.

METHODS OF STUDY.

AREAS STUDIED.

The characteristics and the reproduction of Douglas fir have been studied by the Wind River Forest Experiment Station staff for the past 10 years. Field studies have been made, and laboratory results have been verified throughout the Douglas fir region of Oregon and Washington.

Not only has a general survey been made of most of the large forest burns and a number of smaller burns in the Douglas-fir region of Oregon and Washington, but also a close study of about 875,000 acres located in various parts of the region, including large and small burns has been made. The effects of one forest fire and one or more reburns on the same area were analyzed as well as the effects of season and methods of slash burning and of one or more slash fires on the same area.

THE TRANSECT.

In the field studies the belt transect, 8¼ feet wide, was generally used. On these transects the age, species, and condition of each seedling found were noted. The rod-square plot was also used to a large extent both for permanent and temporary records.

For an intensive study of an area, belt transects were run 2½ chains apart over the entire area, and in this way an actual examination of 5 per cent of the total area was made. For an extensive study two transects were run 2½ chains apart over the parts of the area that obviously afforded the best average conditions. A total of 1,223 temporary and permanent rod-square plots and 109.9 miles of belt transect 8¼ feet wide formed the basis for the conclusions reached through field studies.

INSTRUMENTS.

All records of temperature in fires and in the heat treatment of seeds or cones were taken with the Leeds and Northrup portable potentiometer. In the field the iron-constantin lead wire was used and the iron-constantin and chromel-alumel thermocouples. The chromel-alumel and copper-constantin thermocouples were used in the laboratory, but no lead wires were required. The potentiometer, thermocouples, and wire were tested and standardized by the Bureau of Standards at Washington, D. C. The copper-constantin thermocouples were used for some of the readings in tests of cones and inflammability. For the inflammability tests the same inflammability apparatus was used that had been used in the tests at the Forest Products Laboratory of the Forest Service at Madison, Wisconsin. Standard thermometers were used for soil and air temperatures. Evaporation records were taken with the Forest Service Evaporimeter and by the open tank method. For the laboratory tests of heat resistance of seeds in cones, the inflammability point of needles and twigs, and the heat resistance of bark, the apparatus was arranged as shown in Plate XVIII.

APPENDIX B.

BOTANICAL CHARACTERISTICS.

Only those characteristics of Douglas fir are considered that affect the distribution and regeneration of the Douglas-fir forest.

FLOWERS.

The pistillate flowers are borne at the ends of the branches, just back of the terminal buds, on distinct stalks one-eighth to one-fourth inch long. The staminate flowers are borne on the preceding season's growth, farther back than the pistillate flowers, on stalks one-eighth to one-fourth inch long. They usually mature before the pistillate flowers. The Douglas fir is pollinated entirely by wind, and this development and arrangement of flowers decreases the chance for self-pollination. (Pl. XIX, fig. 1.) The flowers are monoecious and diclinous.

FRUIT.

The cones are pendent on stalks one-fourth to three-fourths inch long and about one-eighth inch in diameter. The cones are generally 1½ to 5 inches long and about 2½ to 3 inches in diameter. They are about 1½ inches in diameter near the base, with a gradual taper to the rounded point. The trident bracts extend from one-fourth to one-half inch beyond the scales, with the center point about one-fourth inch longer than the side points. Two winged seeds are borne under each scale. (Pl. XIX, fig. 2.) The cones mature in one season and are ripe in late August or early September. The seeds are shed within a few weeks after maturity, but some good seeds may remain in the cones for more than a year. Seeds that do not contain endosperm, and are consequently infertile, are often not shed until winter, and when they leave the cones they may, because of their lightness, be widely distributed over the snow by wind. The average number of seeds per pound is about 38,000.

The cones do not open appreciably until they lose about 35 per cent of their green weight in moisture. They open best when 40 to 50 per cent has been evaporated.[1] When the cones are exposed to intense heat, they do not open as well as when evaporation occurs more gradually. Sometimes cones that have passed through fire remain closed.

BUDS.

The buds are dark russet-brown when mature. Greenish buds are subject to frost injury.

LEAVES.

The leaves are three-fourths to 2 inches long. They are grayish green beneath and dark green on the upper side. On older branches they are slightly flattened with rounded points; on seedlings they are slender with acute points; and on terminal shoots the leaves are flattened with short points. (Pl. XX, fig. 1.)

The leaves are persistent for several years, some remaining for seven years in the open and older stands, although very few remain more than three years in the thrifty young or dense stands. The cotyledons or seed leaves are linear with a tapering point. The number varies from six to nine. (Pl. XX, fig. 2.)

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[1] Willis, C. P. Incidental Results of a Study of Douglas Fir Seed in the Pacific Northwest. Journal of Forestry, vol. 15, No. 8, p. 991. 1917.

FORM.

The crowns of open-grown trees with good growing space are pyramidal and become broadly rounded or flat-topped in old age. In forest stands the boles are usually clear of branches for more than one-half the height of the trees. The clearing of side branches begins at an early age in complete stands, but in open-grown trees these branches are persistent and become large. The usual diameter of mature trees is 3 to 4 feet, and the height is 175 to 250 feet. Trees even larger than this are common. The largest authentic diameter recorded is 13 feet at 6 feet above ground, and the greatest height is 325 feet.

BARK.

On trees 10 to 15 years old the bark is about one-fourth inch thick, smooth, lustrous, and grayish to brown. It becomes ridged on trees about 30 years of age, and on old trees it grows to be 8 to 14 inches thick, dividing into large, rounded, irregular connected ridges. Some old trees have bark 18 to 24 inches thick at the base. The bark scales off and forms mounds around the bases of the trees. These mounds make good insulation against fire.

WOOD.

The wood is light red or yellow, with heavy white sapwood. The seedlings become lignified when 30 to 40 days old and at that age begin to be resistant to "damping-off" disease.

LONGEVITY.

Stands 300 to 450 years old are common, and some stands older still have been noted in the region studied. The best development of the tree is during the first 200 years. The oldest tree noted was 739 years of age.

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