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Natural Regeneration in the Western White Pine Type

By

IRVINE T. HAIG
Principal Silviculturist

KENNETH P. DAVIS
Senior Silviculturist

and

ROBERT H. WEIDMAN
Senior Silviculturist

Northern Rocky Mountain
Forest and Range Experiment Station
Forest Service

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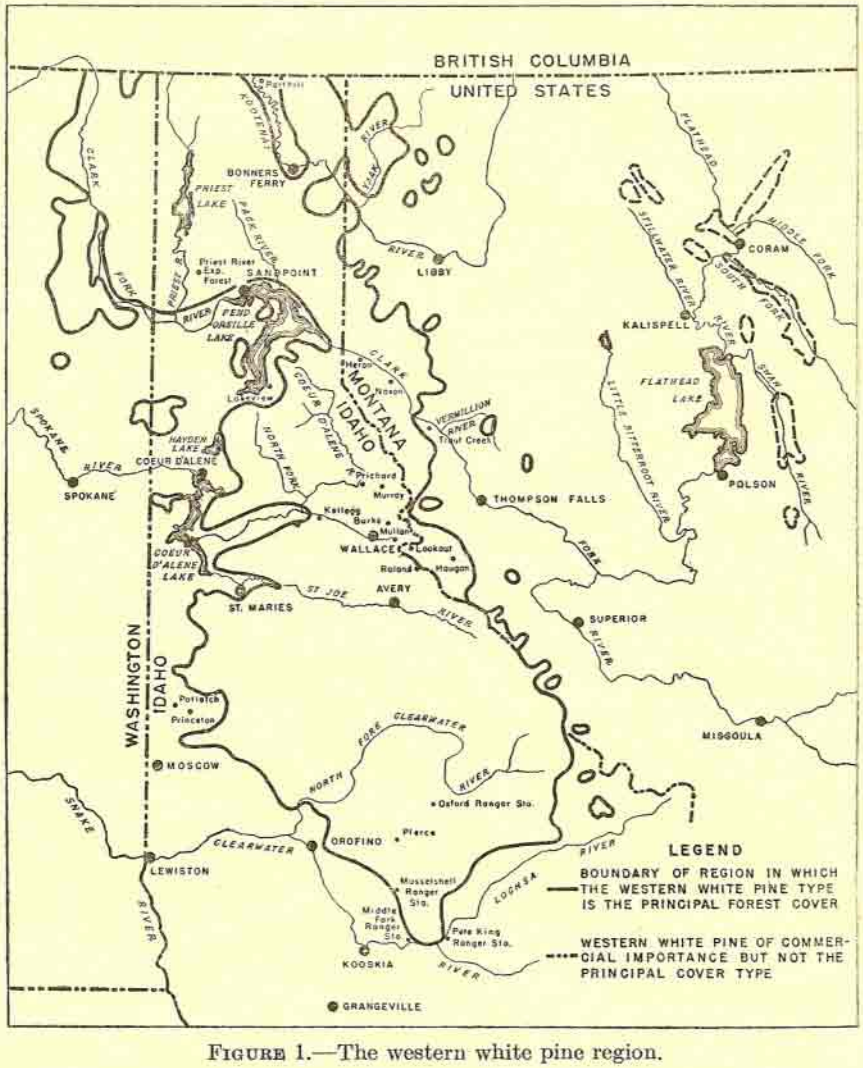

FIGURE 1.—The western white pine region.

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Natural Regeneration In The Western White Pine Type[1]

By IRVINE T. HAIG, *Principal Silviculturist*, KENNETH P. DAVIS, *Senior Silviculturist*, and ROBERT H. WEIDMAN, *Senior Silviculturist, Northern Rocky Mountain Forest and Range Experiment Station, Forest Service*[2]

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INTRODUCTION

The purpose of this bulletin is to bring together the available information on natural regeneration of the western white pine type, based on about 25 years of forest research and 30 years of national-forest timber-cutting experience.

Western white pine (*Pinus monticola*) forms the key species of the valuable western white pine type of northern Idaho and contiguous portions of Washington, Montana, and British Columbia. Although

[1] Received for publication June 20, 1940.

[2] The writers wish to acknowledge their indebtedness to a number of men who have contributed to the studies reported here; to D. R. Brewster, first director of the Priest River Experiment Station, now the Northern Rocky Mountain Forest and Range Experiment Station; to J. A. Larsen and the late Robert Marshall, formerly members of the station staff; to Gerhard Kempff and J. B. Thompson, successive resident officers at the Priest River experimental forest; to many forest administrative officers, particularly Elers Koch, W. B. Greeley, C. K. McHarg, Philip Neff, M. H. Wolff, and F. I. Rockwell; and to a number of pathologists and entomologists, particularly J. R. Weir, E. E. Hubert, S. N. Wyckoff, and J. C. Evenden.

the species has a rather extended geographic distribution as a species (fig. 1), the region [3] in which it is the most important constituent of a dominant forest type is relatively restricted, as shown in figure 2. In many localities outside its area of abundant occurrence, western white pine grows well and makes excellent development as a timber tree, but for the most part it is a minor constituent of the forest.

Native to a region characterized by precipitous topography, the type occurs largely in irregular, often attenuated bodies following the more moist creek bottoms, lower benches and flats, and northerly slopes (pl. 1), often forming intricate ground patterns, as is well illustrated in figure 3. Various accidents of stand origin and development have also contributed to the "crazy-quilt" occurrence of the type within much of the region. Instances of more extensive bodies are found chiefly in the broader river valleys, like that of the Priest River, and on the smoother lower slopes, such as those between St. Maries and Orofino, along the western border of its range.

Commercial stands of western white pine are confined to a total range of some 2,700,000 acres.[4] Within this area the principal associate species are western larch (*Larix occidentalis*), Douglas-fir (*Pseudotsuga taxifolia*), grand fir (*Abies grandis*), western redcedar (*T uja plicata*), and western hemlock (*Tsuga heterophylla*). Frequent associates are Engelmann spruce (*Picea engelmannii*), alpine fir (*Abies lasiocarpa*), lodgepole pine (*Pinus contorta latifolia*), and ponderosa pine (*P. ponderosa*), but these are important components of the type only in restricted localities. The species composition of the western white pine type is exceedingly variable, ranging from almost pure white pine to every conceivable combination with its associated species. It may even include many individual stands dominated by other species and yet retaining at least 15 percent of white pine.

Relatively small but highly productive, the western white pine region sustains a major manufacturing industry in northern Idaho, northeastern Washington, and western Montana. Western white pine exceeds all other species logged in that region in both volume and value. "Lumbering in the greater part of north Idaho, with the comparatively high logging costs encountered, is made possible only through the high value of the white pine" (*32*).[5] On January 1, 1936, it was estimated, the total volume of western white pine saw timber amounted to 13,887 million board feet, lumber tally, or nearly half the merchantable volume of the type. In 1925–34 the average annual cut of this species totaled about 430 million board feet, lumber tally, and had a value of approximately $14,000,000. In addition to being used extensively for lumber, western white pine is valued as a special-purpose wood. Nearly one-quarter of the total annual cut is used in manufacturing matches.

Western redcedar is the second most important species in the region. Its commercial occurrence practically coincides with that of western white pine. "Cedar" poles, used for electric power transmission lines, telephone lines, etc., are worth considerably more than western

[3] Throughout this bulletin, region will refer to the general area within which the western white pine type is the principal forest cover, and type to the western white pine type proper, as defined by the Forest Service, namely, as mature timber stands containing 15 percent or more western white pine volume, or immature stands containing 15 percent of more western white pine by number of trees.

[4] This is the approximate extent of western white pine zone 1, both on and outside the national forests. Zone 1 timber, as defined by the Forest Service, is timber of such species, condition, and location that, under economic conditions such as have prevailed in the past and with normal development of transportation facilities, it could be logged at a profit.

[5] Italic figures in parentheses refer to Literature Cited, p. 95.

FIGURE 2.—Geographic distribution of western white pine.

white pine on a log-scale basis. Annual production of these poles amounts to more than 15 million linear feet; this equals 44 million board feet and constitutes 63 percent of the total average annual cut of "cedar." Other principal redcedar products are sawlogs, fence posts, piling, and shingles, and the annual total value of these and the poles is about $2,000,000. White pine and redcedar together constitute almost exactly 50 percent, by value, of all forest products annually produced in the Inland Empire. Of the remainder, ponderosa pine makes up 28 percent and other species, principally Douglas-fir and western larch and to a lesser degree Engelmann spruce and grand fir, 22 percent. None of the species commonly associated in the type, aside from white pine and redcedar, now command log prices high enough to warrant extensive logging.

In view of the low value of these lesser components of the type and the heavy investments necessary to protect these forests from fire and disease, it is important that the reproduction of valuable species be encouraged and the forests maintained in productive condition. A knowledge of the factors controlling natural regeneration is necessary to achieve this end.

HISTORY OF EARLY INVESTIGATIONS AND PRACTICES

The creation of the Forest Service in 1905 marked the first formal step toward the practice of silviculture over extensive land areas in the Western States. Charged with the duty of managing the national forests for permanent usefulness, this organization was immediately faced with the necessity of working out forest-cutting practices for virgin stands which would insure adequate regeneration with desirable species. At that time little was known of the silvical habits or requirements of the associated tree species. Available information was limited to observations made on reproducing burns or other natural breaks in the virgin forest, or on the few cuttings that had been made on privately owned lands. Some of this observational material was published by Leiberg (*42*, *43*, *44*) around 1900, in a series of interesting papers on forest conditions in northern Idaho, bearing on the silvical requirements of the principal species.

One of the earliest projects of the newly organized Forest Service was a planned effort to supplement on a wide scale the general knowledge of these northern forests. The technical staff assigned to each national forest was required to report annually their observations on the character and occurrence of natural reproduction and the conditions apparently encouraging or discouraging its establishment.[6] The fund of information thus built up was soon augmented by the results of large-scale trial-and-error experiments in the form of actual cutting operations under technical supervision. Within the first 5 years of Federal supervision, five very different methods of cutting were tried in the western white pine type.

In the first national-forest timber sale [7] in the western white pine type in 1907, on Fidelity Section 20 of the Kaniksu National Forest, the scattered-seed-tree method was used. The area was clear cut except that one to five thrifty dominant western white pine trees per

[6] Unpublished reports by R. L. Fromme (1907), J. R. Gillis (1912), W. R. Morris (1911), and F. I. Rockwell (1912) are especially informative.

[7] Timber in a national-forest timber sale is sold to the highest bidder, who contracts to cut the timber as specified by the Forest Service.

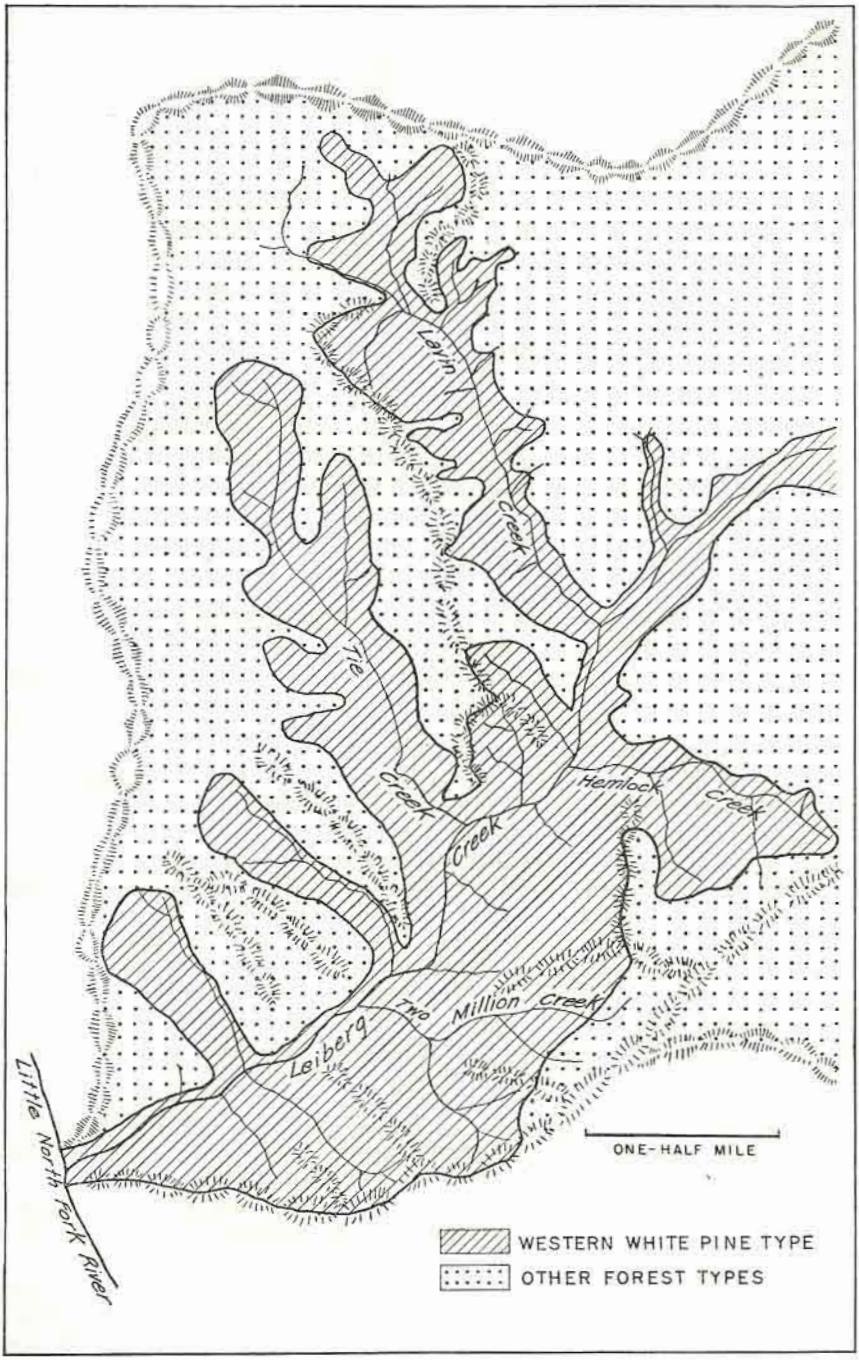


FIGURE 3.—Distribution of the western white pine type in a typical drainage in northern Idaho.

acre were left for reseeding. Unfortunately, these trees were soon blown down, and this led forest officers to the belief that western white pine was not wind-firm and could not be left safely except in compact blocks or strips. Accordingly, in the belief that western white pine was not wind-firm, that it was a prolific seeder capable of reproducing itself readily up to distances of one-half mile or more, and that it required a mineral seedbed for best germination (*7*),[8] it was specified in subsequent sales on the Kaniksu National Forest in 1907–10 that the timber should be clearcut and the regeneration should be provided for by leaving 2- to 20-acre blocks of uncut timber, 250 to 1,300 feet apart, advantageously situated to disseminate seed over the cut-over area.[9] Furthermore, the slash on the cut-over portion was broadcast burned.

On the Coeur d'Alene National Forest, at about the same time and after several other methods of cutting had been tried, timber-sale officers decided that some clear-cutting system would be preferable. The partial-cutting methods previously tried, including a rough diameter selection and a crude shelterwood method that left about 100 of the larger trees per acre, were found to require too much time for careful tree marking and to present practical difficulties of logging and subsequent slash disposal. The belief also grew that the shade of the residual stand would favor the low-value grand fir and hemlock over pine.

Clear-cutting here assumed a somewhat different form from that on the Kaniksu forest, the reserved stand consisting of strips about 150 feet wide alternating with clear-cut strips from 300 to 450 feet wide. Excellent regeneration took place on the Coeur d'Alene strip cuttings, whereas the Kaniksu seed-block cuttings often failed to restock satisfactorily, owing in part to the more severe environmental conditions on the level and open valley lands where these cuttings were made, and in part to the relatively wide spaces between sources of seed.

These two clear-cutting methods had certain faults in common. First, they proved economically unsound, a matter to which technical men gave scant consideration in the first stages of developing silvicultural practices (*9*). The logging operator, forced to distribute his costs over only about 75 percent of the total volume of merchantable timber and required to cut any tree that would make a 16-foot log to a 6-inch top, even in species of low commercial value, often experienced financial difficulties. Second, no adequate provision was made for final cutting and regeneration on the uncut strips or blocks, though these invariably contained mature or overmature timber which it was silviculturally undesirable to let stand through another rotation. Third, the broadcast slash fires were hard to handle and occasionally got away to destroy seed blocks or other green timber.

Regardless of their relative advantages and disadvantages, however, the clear-cut-and-seed-block and clear-cut-and-seed-strip methods were not widely employed. On the Coeur d'Alene forest, severe fires in 1910 caused an interruption of several years in timber-sale operations. On the Kaniksu forest the first formal timber-marking rules, drawn up in 1912, prescribed clear cutting as practiced on the

[8] CARY AUSTIN A SILVICULTURAL STUDY IN WESTERN WHITE PINE STANDS, KANIKSU NATIONAL FOREST. File memorandum. U. S. Dept. Agr., Forest Service. 1911.

[9] For the ground plan for one of the largest of these early Kaniksu cuttings, see Graves (*16, fig. 23*).

Coeur d'Alene with 25 percent of the stand to be reserved in seed strips running along the ridge crests and up and down slopes at right angles to the main drainage features; cutting on this forest during the next few years was concentrated, however, on so-called agricultural lands, which after being logged were to be thrown open to settlement. For these lands the rules prescribed clear cutting with reservation of only small patches of timber suitable for farm improvements. When more extensive cutting was resumed, about 1912, new information relating to the silvical habits of western white pine had been gained and methods of cutting were soon radically changed.

This information was gained by systematic observation resulting largely from organized research, which began with the formation of the Priest River Experiment Station in 1911 and was concentrated on western white pine. Cut-over areas were gridironed with transect strips run at regular intervals from nearby green timber or seed blocks. Important habitat factors were carefully described and a record was made of the number, age, and location of the tree seedlings found, and of the kind of surface (e. g., duff, mineral, or burnt mineral) upon which germination had occurred. On the basis of its 1912 [10] and 1913 investigations, the station made the following important contributions to silvical knowledge: (1) Long-distance dissemination of western white pine seed was the exception rather than the rule; (2) western white pine does not require a mineral seedbed for satisfactory germination, and consequently broadcast slash burning is not justfied as a means of insuring successful regeneration; (3) western white pine seed probably remains viable for several seasons in the duff under mature white-pine stands. These contributions had an immediate and marked effect upon silvicultural practices in the western white pine region.

The first region-wide timber-marking rules for western white pine, drawn up in the fall of 1913, were based on the theory advanced by Hofmann (*23*) that seed stored in the duff under old-growth forest stands could be depended upon for adequate regeneration after cutting. These rules, prepared by W. B. Greeley, rejected the principle of leaving large strips or blocks of timber uncut as a seed source and placed almost entire dependence upon seed in the duff and whatever advance growth might be present (*47*). Under these rules each sale area was to be clear-cut except that approximately 10 percent of the stand was to be retained in compact groups, principally to provide for reproduction where the surface had been severely burned in slash disposal and to insure restocking in case the first reproduction stand were destroyed by later fire. The seed-tree groups were to be spaced from 200 to 400 feet apart, averaging one group to each 2 acres. The slash was to be piled before being burned, in order to save as much advance reproduction as possible and preserve white pine seed stored in the duff. The rules provided also for girdling unmerchantable species, such as grand fir and hemlock, or destroying them by piling and burning slash around them.

These rules marked two advances not previously mentioned: (1) A growing recognition, based on information collected by Rockwell, Koch, and other forest officers, that western white pine was fairly wind-firm in most situations and could safely be left either in

[10] Annual report of the Priest River Experimental Forest. Northern Rocky Mountain Forest and Range Expt. Sta. 1913. [Unpublished.]

small groups or singly; (2) a square facing of economic requirements by providing for the prorating of logging costs over a larger percentage of the stand and for the disposal of unmerchantable timber.

The 1913 rules, slightly revised, were applied widely on the Coeur d'Alene and to some extent on the St. Joe and Lolo National Forests. Excellent regeneration on a number of areas cut over in 1914 and 1915 bears testimony to their generally satisfactory character when applied on favorable areas and under desirable stand conditions. Forest officers, however, found them undesirably rigid. White pine did not always occur in a manner permitting the reservation of well-distributed seed groups; and retention of a fixed percent of the original stand volume in seed trees often resulted in keeping more or fewer seed trees than silvicultural conditions required. Large numbers of small or unmerchantable trees remaining after cutting on some areas, particularly where timber-sale officers failed to make full use of the marking provisions for the girdling or destruction of unmerchantable species, often obscured the seed-tree groups; some areas cut under the seed-tree-group system could hardly be distinguished from areas cut under a rough diameter-selection system (*45*). Reconsideration of marking-rule requirements was indicated and after considerable preliminary field work in 1915 a regional marking board met for this purpose in May 1916 at Coeur d'Alene.

The 1916 marking board, composed of F. A. Silcox, J. F. Preston, M. H. Wolff, Elers Koch, F. I. Rockwell, C. K. McHarg, and J. Kittredge, Jr., assisted by D. R. Brewster of the experiment station, drew up a set of marking rules (*45*) specifying the adoption of the scattered seed-tree system for mature western white pine stands. The undesirable rigidity of the 1913 rules was avoided by confining the new rules to general guiding principles, provision being made that supplemental rules be prepared to meet the specific needs of each logging chance.

All sound trees of species other than white pine were to be cut to the lowest merchantable size, stumpage prices being adjusted to recompense the logger for the differential between production cost and average selling price of the mixed species. All defective and unmerchantable trees that would interfere with white pine reproduction were to be destroyed by slash burning, girdling, or felling.

Larch, Douglas-fir, redcedar, and spruce were classified as generally desirable associates; and western hemlock and grand fir as undesirable, because of their dense crowns, prolific seeding, tolerance, and tendency to be defective.

The adoption of the 1916 rules culminated some 8 years of intensive effort and investigation on the part of administrative and research officers in the western white pine type. Brewster,[11] summarizing investigative work up to this time for consideration of the marking board, called attention to material progress along several lines. Considerable information had become available on seed production in western white pine stands. For example, observational studies had revealed western white pine as a comparatively light but fairly frequent seeder, producing some cones almost every year with good to abundant crops at intervals of 3 to 4 years. An investigation of seed production conducted by Zon (*68*) in the fall of 1911 had shown that

[11] BREWSTER, D. R. STUDY OF METHODS OF CUTTING IN THE WESTERN WHITE PINE TYPE. Northern Rocky Mountain Forest and Range Expt. Sta. 1916. [Unpublished.]

in a moderately good seed year well-stocked, mature western white pine stands produced 2½ to 5 pounds of germinable white pine seed (75,000 to 150,000 seeds) per acre, and that practically the entire crop was produced by dominant and codominant trees. Later studies by Brewster [12] brought out a definite variation in western white pine seed production with size of tree, the size of the seed crop being in general directly proportionate to that of the tree.

Considerable information had been gathered, between 1912 and 1916, bearing upon the probable source of the seed from which reproduction, usually even-aged, had come in on western white pine areas throughout the region after fires of varying severity and after cuttings that removed most or all of the merchantable timber. As a starting point, three possible hypotheses of seed source were recognized: [13]

(1) Wind-disseminated seed from green timber standing at or near the edges of the area. Early transect studies of reproduction originating from known seed sources on some 30 burns and cuttings had shown that about 70 percent of the white pine seedlings started within 200 feet of isolated parent trees and about 90 percent within 400 feet. Although white pine seed is capable of traveling long distances in exposed, windy situations, it was obvious that restocking by wind dissemination of seed from distant sources would be slow and uncertain. Such trees could therefore play only a minor role in restocking more than a few hundred feet beyond the green timber.

(2) Seed produced by living trees left from cutting or fire. It was doubted that the green trees left standing after fire were in general numerous enough or sufficiently well distributed to produce the abundant seed supply from which had sprung the many dense, even-aged young stands found, though Brewster reported one such instance on the Coeur d'Alene Forest and recorded the fact that in some timber stands subjected to light surface fires in 1910, the tops of a considerable proportion of the trees remained green for 3 years after the fire.

(3) Seed produced before cutting or fire and stored in the surface duff and litter until after cutting or burning occurred. Although Brewster noted that all three sources might play a part in regeneration, seed in the duff, particularly stored seed carried over from former seed crops, made a strong appeal to the imagination of the average forest officer and drew more than its share of attention and study for almost a decade after the 1916 rules were prepared. Transect studies had furnished unquestionable evidence that seed in the duff from an immediately preceding seed crop or from an earlier crop had played a part in reproduction on cut-over and burned-over areas throughout the western white pine region. Some areas examined in the course of these studies on which cutting had left few, if any, white pine trees capable of bearing seed, but which had not been broadcast burned following cutting, supported excellent stands of seedlings from 1 to 4 years old. Most of these seedlings had germinated 2 years after cutting, presumably from stored seed. On partially burned areas it was found that most of the seedlings present, except those within a few chains of green timber, had germinated on lightly burned or unburned duff. Additional evidence was presented by Larsen, who

[12] BREWSTER, D. R. WESTERN WHITE PINE SEED PRODUCTION. Northern Rocky Mountain Forest and Range Expt. Sta. 1916. [Unpublished.]

[13] ——— RESEARCH METHODS IN THE STUDY OF NATURAL REPRODUCTION Northern Rocky Mountain Forest and Range Expt. Sta. [n. d.] [Unpublished.]

took up sections of undisturbed duff from beneath mature and overmature timber stands near the Priest River station headquarters in August 1913, and found that the top layer of duff contained between 900 and 5,000 viable white pine seeds per acre.[14] How much of this seed had come from the light seed crop in 1912, and how much from previous crops, it was impossible to say; but as the duff samples were gathered in August, before the 1913 crop could have been released, it was certain that this seed had already remained viable somewhat longer than the normal overwinter period. On the basis of these studies Brewster estimated that the duff on old-growth western white pine areas at the time of cutting contained, on the average, 2,900 viable white pine seed per acre.

In addition to the evidence on seed production and seed source, considerable information had been gathered upon other silvical features of importance. The indication appeared clear that white pine could germinate and survive with fairly good success on all the common ground surfaces, including bare mineral soil, duff, and rotten wood. Though pine would germinate under heavy shade, it appeared that 50 percent of full sunlight was about the minimum for good growth and development. On the other hand, if moisture conditions were favorable, white pine would germinate and develop best in full overhead light. It had been found also that a surface cover of herbs and shrubs, unless it was unusually dense or tall or the roots formed a compact sod, did not seriously interfere with the establishment of white pine seedlings, and that western white pine, if given an equal start with other species, would hold its own and form a considerable portion of the dominant stand at maturity. Perhaps of even more importance was the fact, gradually recognized, that white pine was reasonably wind-firm, even though occasional heavy windfall might occur. It had been learned that white pine trees were easily killed by even light surface fires, and consequently could not be relied upon, as the 1913 rules contemplated, for seed production on areas accidentally burned following logging.

Similar information, though much less detailed, had been gathered for the principal associated species in the western white pine type.

The 1916 marking rules proved generally satisfactory, and with some important modifications are still employed in national-forest timber sales in the western white pine type. These rules were somewhat indefinite, however, as to what constituted a good seed tree, and in some cases reproduction following cutting on areas logged under them has been relatively poor because undue confidence was placed in the seeding ability of trees less than 14 inches in diameter at breast height.[15] In addition, evidence [16] steadily accumulated that stores of seed in the duff could not be entirely depended upon. As a result, the conviction grew among timber-sales officers that seed trees played a larger part in the successful regeneration of white pine than the current marking rules assumed.[17] Accordingly, each subsequent revision of the rules defined seed-tree requirements in greater detail and on a higher standard. Marking rules in effect in 1937 [18] specified

[14] Annual report of the Priest River Experimental Forest, Northern Rocky Mt. Forest and Range Expt. Sta. 1913. [Unpublished.]

[15] Diameter measured 4.5 feet above the ground; abbreviated, d. b. h.

[16] BREWSTER, D. R., NATURAL STORAGE OF WESTERN WHITE PINE SEED. Progress report. Northern Rocky Mountain Forest and Range Expt. Sta. 1917. [Unpublished.]

[17] HAIG, I. T., STUDY OF CUT-OVER AREAS IN THE WESTERN WHITE PINE TYPE. Northern Rocky Mountain Forest and Range Expt. Sta. 1925. [Unpublished.]

[18] U. S. DEPARTMENT OF AGRICULTURE, FOREST SERVICE. TIMBER MANAGEMENT HANDBOOK, REGION 1 139 pp. 1932. [Mimeographed.]

that in mature stands two to six thrifty white pine trees, preferably 16 inches or larger in d. b. h., be left per acre, the minimum number being left only if the trees were 20 inches or more in d. b. h., and had large crowns. Silvicultural research (*41*) and the experience of administrative officers charged with fire protection indicated the desirability of piling and burning most logging slash on cut-over areas in the western white pine type, and this practice became and has remained standard for national-forest timber sales.

Most of the discussion since 1916 regarding silvicultural practice in the western white pine type and the changes evolved have centered around the so-called inferior species (*31, 50*)—the considerable proportion of most merchantable stands that is composed of trees of low or negative stumpage value. The low values are due to high susceptibility to heart rot of western hemlock, grand fir, and some other species (*24, 64, 66, 67*), and to the fact that the selling price of lumber manufactured from these species is often insufficient to meet production costs even if nothing were paid for the standing timber. Where trees of such species are not defective, the Forest Service policy has been to leave them uncut in the hope that at some future time they can be sold at a profit. For this reason, areas supporting large volumes of sound timber but of unmerchantable species have been excluded from Forest Service timber-sale boundaries. But leaving these low-value species on areas that are cut over encourages their reproduction and tends to decrease the proportion of western white pine in the reproduction—an undesirable result both silviculturally and economically. Western white pine is the most rapid in growth, and its wood, because of inherently desirable characteristics, brings a better market price than that of any of the associated species with the single exception of redcedar for poles. The lumber-price differential between western white pine and its most valuable saw-timber associates, western larch, Douglas-fir, and grand fir, is from $12 to $15 per thousand board feet. In the past, this price differential has persisted despite fluctuations in the general price level.

Girdling (*6*) proved to be an effective and economical method of killing undesirable trees and was extensively employed, particularly on the Coeur d'Alene National Forest, during 1916 and in ensuing years. Silviculturally it proved entirely satisfactory on most white pine sites. Larsen (*34, 37*) presented evidence, however, that extensive girdling, resulting in removal of practically all overwood shade, was silviculturally undesirable on drier sites such as flats and southerly slopes, and the transect studies reported by Haig [17] demonstrated clearly that reproduction on such sites was often unsatisfactory. On some other sites, although economical and silviculturally satisfactory, girdling conflicted directly with protection requirements, as the trees so killed later constituted a dangerous fire hazard.

A compromise among silvicultural, economic, and fire-protection aims was made in 1923 by so modifying earlier practices as to limit the number of trees per acre that could be girdled. In 1924, the marking rules were revised to specify that cutting operations in mature stands should leave a 5 to 15 percent crown cover on flats, and a 15 to 25 percent crown cover on southerly slopes. This required leaving 7 to 35 medium-sized trees of the desirable associates, such as western larch, Douglas-fir, western redcedar, and Engelmann

spruce or making up this number, if necessary, with trees of the less desirable species. All other unmerchantable or defective trees were to be felled and the brush piled and burned, except that not more than 12 per acre of the larger trees might be killed. The silvicultural wisdom of this revision has been confirmed by a more recent study (*19*), which definitely showed the need for shelter during regeneration on the more severe sites.

Although the 1924 rules proved satisfactory from a silvicultural standpoint, pressure of economic considerations necessitated some readjustments. The wisdom of forcing sound mixed species onto the lumber market when these species would not pay their share of production costs and could be logged only if stumpage prices were reduced, has always been questionable. At the present time every effort is made to avoid cutting timber stands containing considerable proportions of sound timber of unmerchantable species. The 1932 marking rules as modified specify that if such stands are cut, timber of mixed species need not be taken unless it will pay its way. Although leaving large volumes of mixed species tends to decrease the proportion of white pine in the reproduction stand, investigations have shown that white pine will germinate and will develop fairly well in its early years under a rather heavy residual stand (*19*).[19] Consequently, if the residual stand is removed within 15 to 20 years following logging and cultural measures are applied to correct unsatisfactory composition of the reproduction stand, there is reason to expect satisfactory white pine reproduction regardless of the large volume originally left following logging.

Another development of recent years is the restoring to productivity of areas supporting overmature and decadent stands by cutting all merchantable timber, felling and broadcast burning the remaining stand, and, unless conditions are especially favorable for prompt regeneration, planting after burning. This practice is later discussed under clear cutting.

COMPOSITION AND CHARACTER OF FOREST

That many of the silvicultural problems encountered in the western white pine type are due to the association of a number of tree species differing considerably in their silvical characteristics and requirements, has already been made clear. The type unites western hemlock and western redcedar, characteristic species of the Pacific Coast forests, with western larch, the Rocky Mountain form of Douglas-fir, and lodgepole pine, typical of the northern interior forests.

Compositional variations of the type are related to geography (table 1). Western larch, for example, is less abundant in the central and southern portions than in the northern portion of the type's commercial range, and is entirely lacking in many of the pine stands of the Clearwater River drainages, where the proportion of pine is higher. Western hemlock practically disappears in the southern portion, but abounds in the central and northern portions. Grand fir, though an important component of most western white pine stands throughout the region, is less plentiful in the northern than in the

[19] HAIG, I. T. PRELIMINARY NOTES ON REPRODUCTION FOLLOWING LOGGING IN THREE STANDS CONTAINING HEAVY ADMIXTURE OF SECONDARY SPECIES. File memorandum. Northern Rocky Mountain Forest and Range Expt. Sta. 1928. See also footnote 18.

central and southern portions, where it sometimes forms the dominant cover over considerable areas. Western redcedar, though found throughout the commercial range of western white pine, is primarily confined to river flats, benches, and moist north slopes. Redcedar is occasionally lacking on sites of all classes over considerable areas; for example, it does not occur in commercial quantities in any part of the North Fork drainage of the Coeur d'Alene River, though common in nearby drainages. Douglas-fir is a common component of young to mature stands throughout the region. Ponderosa pine, although the characteristic species of a timber type occurring widely both to the east and to the west of the western white pine region, seldom is found in significant quantities in this region except along the borders, on the drier sites such as south slopes. Ponderosa pine is not commonly associated with western white pine and has little importance in the silvicultural management of white pine stands. The small proportions of western hemlock and western redcedar shown in table 1 may make it seem strange that these species are considered important in the management of the type, the former as a problem and the latter as the second most valuable species. The explanation is that these species are abundant on the better-quality sites where timber cutting has been largely concentrated, although not widely distributed over the region as a whole.

TABLE 1.—*Species composition of timber stands in the western white pine region*

Species	Second-growth stands [1]				Mature stands of region as a whole [2]
	Northern	Central	Southern	Average	
	Percent	*Percent*	*Percent*	*Percent*	*Percent*
Western white pine	45	46	55	49	45
Western larch	24	10	7	14	8
Douglas-fir	11	12	15	13	12
Grand fir	3	13	12	9	14
Western hemlock	5	7	1	4	3
Western redcedar	6	2	2	3	4
Engelmann spruce	2	2	1	2	4
Lodgepole pine	3	7	6	5	1
Ponderosa pine	1	1	1	1	9
Total	100	100	100	100	100

[1] Basis, data obtained through comprehensive growth, yield, and stocking studies made in stands from 30 to 120 years old containing 15 percent or more of western white pine by volume, throughout the type's commercial range.

[2] Basis, Forest Survey check cruises aggregating nearly a billion board feet, Scribner rule. These check cruises thoroughly sampled the forests of the western white pine region as a whole; they were not confined to the western white pine type.

Fire, disease, site quality, and various accidents of stand origin often obscure these geographic trends in forest composition. In second-growth western white pine stands larch, hemlock, "cedar," and grand fir are common associates on flats and northerly aspects, whereas grand fir and Douglas-fir are common associates on southerly aspects. Larch and Douglas-fir are found frequently on upper slopes and ridges. In addition to areas classed as of the western white pine type, there are extensive areas that, because of various vicissitudes of stand origin and development, now contain practically no white pine but are capable of producing stands with a good proportion of white pine.

In density and luxuriance of tree and plant growth, western white pine stands often resemble the forests of the Pacific Coast (pl. 1) and are

definitely unlike the thinner and more open-canopied ponderosa pine, lodgepole pine, and larch-fir forests of the Northern Rocky Mountains. Basal areas [20] of from 250 to 300 square feet per acre in well-stocked second-growth stands are common. Timber stands often reproduce with exceeding abundance; seedlings are numbered usually in thousands and occasionally in hundreds of thousands per acre. Stands 50 years of age often contain 3 to 6 thousand trees 1 inch or more in d. b. h. per acre. In volume, western white pine stands rank well among the better conifer timber stands of the country. Gross volumes (all species) of 40 to 60 thousand board feet Scribner rule (6,500 to 9,800 cubic feet) per acre are found over considerable areas of old-growth forest. (Usually, however, such volumes are less than 50 percent white pine.) One of the first impressions received by a visitor to the white pine region is the abundance of wood, in trees both live and dead, standing and down. The combination of dense timber stands, steep slopes, and thick underbrush in forest openings often justifies the local term "Idaho jungles."

A factor contributing largely to the density of western white pine stands is the intermixture of species varying markedly in tolerance. The principal species of the type range approximately as follows in this respect, from least to most tolerant:

Intolerant	Ponderosa pine. Western larch. Lodgepole pine.
Moderately tolerant	Douglas-fir. Western white pine.
Tolerant	Engelmann spruce. Alpine fir. Grand fir. Western hemlock. Western redcedar.

Western white pine is almost exactly at the midpoint of the series in tolerance. Stands are often two-storied, with white pine, larch, Douglas-fir, and grand fir in the overwood and the more shade-enduring hemlock and redcedar occurring chiefly as an understory.

Western white pine stands tend to be even-aged. This tendency is especially strong for stands less than 120 years of age and for the less tolerant species, particularly larch, lodgepole pine, Douglas-fir, and white pine. These species usually reproduce rather promptly or not at all following fire, epidemic disease, or other major forest disturbance. In most stands less than 120 years of age, a span of 20 years includes 75 percent or more of the trees of these species. Grand fir, hemlock, and redcedar, however, germinate and survive for an indefinite period under relatively heavy shade, and these species often reproduce over an extended period of years. Reproduction stands originating after partial opening of the stand such as is caused by wind, endemic disease, insect attack, or light burns consist principally of these more tolerant species. As a result of these tendencies the overstory of second-growth western white pine stands is usually very nearly even-aged, though sometimes consisting of two or three fairly well-defined age classes. Usually an understory is present, made up of the most tolerant species, including a much wider range of ages than the overstory. A true all-aged condition, such as is often found in ponderosa pine stands, is rare.

[20] Basal area is the cross-sectional area of the tree stem at a height of 4½ feet above ground.

Subordinate vegetation is scanty under the denser stands. Characteristic species are the shade-enduring wildginger (*Asarum caudatum*), queencup (*Clintonia uniflora*), western goldthread (*Coptis occidentalis*), bunchberry (*Cornus canadensis*), twinflower (*Linnaea americana*), clubmoss (*Lycopodium* spp.), myrtle boxleaf (*Pachystima myrsinites*), pyrola (*Pyrola* spp.), false Solomonseal (*Vagnera* spp.), and violet (*Viola orbiculata*). In openings and along streams the species greatly increase in abundance, with such shrubby genera as *Acer*, *Alnus*, *Ceanothus*, *Cornus*, *Lonicera*, *Ribes*, *Rubus*, *Salix*, and *Vaccinium* most in evidence. Following logging or especially fire, a profusion of these shrubby species ordinarily develops. Permanent or semipermanent encroachment of these species on denuded timberlands is in some places a serious problem. There are at least a million acres of once very productive timberlands on or near the St. Joe and Clearwater National Forests—principally along the western side—upon which a dense brush cover has become established following severe logging or fire. Over much of this land, natural regeneration of timber species is not satisfactory and artificial reforestation would be difficult and expensive.

Forest Succession

An account of forest succession in natural stands will help to illuminate the silvical relation and interaction of the several species composing the western white pine type. A knowledge of successional trends is extremely helpful in obtaining satisfactory natural regeneration, since management methods to a large degree only modify and adapt to human needs Nature's crude, often slow, frequently wasteful, but usually effective methods.

Following fire, which is by far the most potent factor in destruction of western white pine stands, abundant natural reproduction containing varying proportions of white pine and associated species usually becomes established (pl. 2, *A*). The composition is controlled by the interaction of site quality, aspect, season, seed source, and like factors. If the burn is very severe, or if it follows closely upon a previous burn, western larch and lodgepole pine are often the first species to become established, and sometimes the only ones for a number of years. Both these species are hardy and make exceptionally rapid and vigorous early growth. Western larch gets its prompt start from seed scattered by veteran trees, which, because of their exceptionally thick bark, survive fairly severe forest fires; lodgepole pine, from the abundant seed supply stored in cones on the parent trees and released when the fire, after killing the trees, opens the cones. Lodgepole pine frequently acts as a pioneer species in reforesting areas that have been badly burned. The Jack Pine Flats near Coolin, Idaho, on the Kaniksu National Forest, furnishes an excellent example (pl. 2, *B*); even a casual inspection shows that the dense stand of lodgepole that followed a very severe fire about 1850 is gradually being replaced by white pine, western larch, Douglas-fir, grand fir, and Engelmann spruce, which in all probability occupied the area before the fire. On the great 1910 burn in northern Idaho, extensive areas originally supporting typical white pine forests are now covered with the lodgepole pine type, but the more characteristic

species of the white pine type are already in evidence and, particularly on the better sites, are gradually supplanting the lodgepole pine.

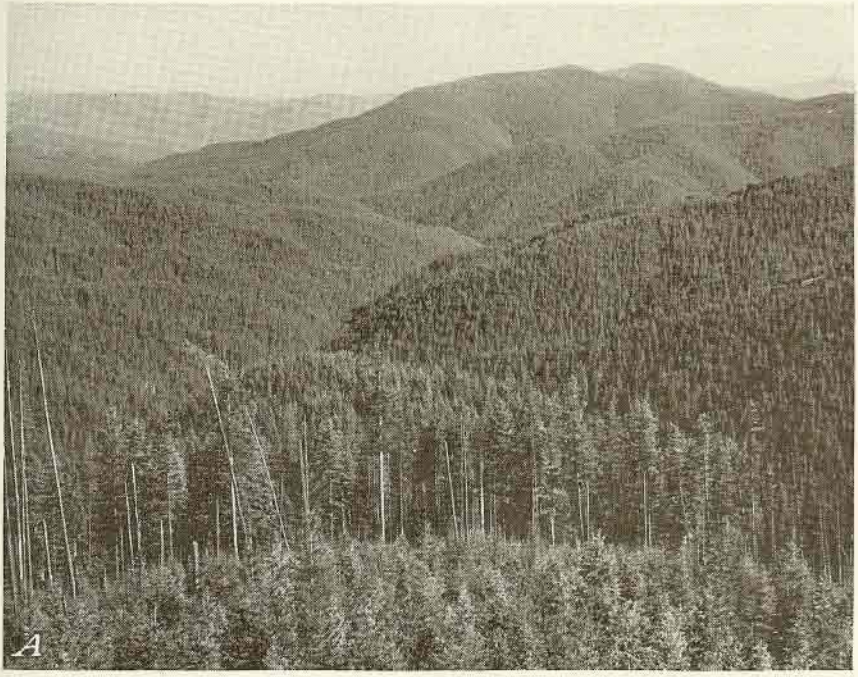
Western white pine, also, has the capacity to reproduce itself vigorously and, given an adequate seed source, will readily establish itself on open burns. In fact, many of the best western white pine stands originated following severe burns on which through some circumstance an abundant seed supply was available. Reproduction following a single burn is usually adequate and the proportion of white pine satisfactorily high. Abundant reproduction of very desirable composition is a common sight on burns filled with fire-killed trees. Unfortunately, however, such areas are sometimes burned over a second or even a third time. After multiple burns regeneration sometimes fails over a long period of years, and is usually scanty and frequently of undesirable composition. Double or triple burns usually leave no living tree for seed source. Serious site retrogression may result.

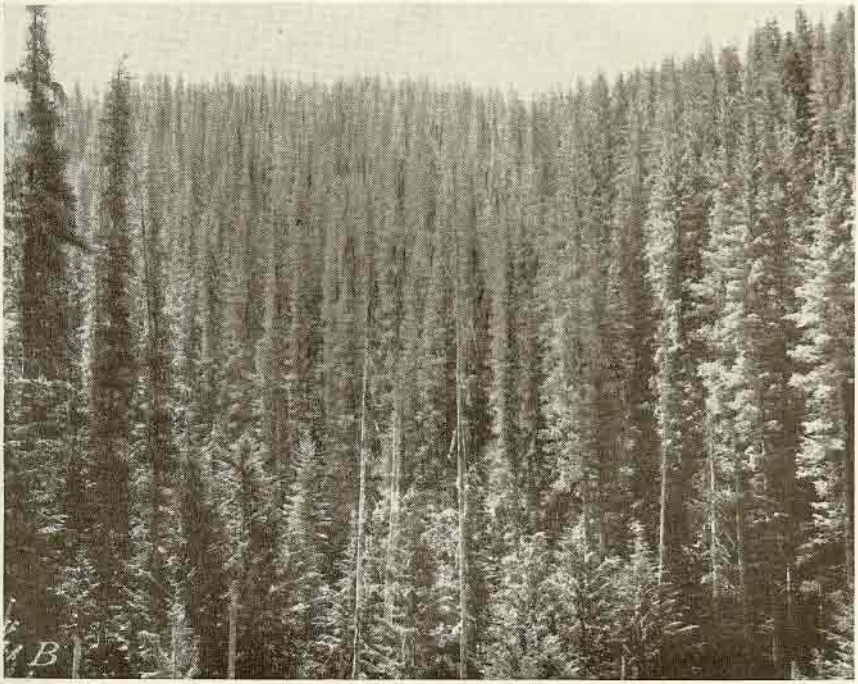
On the more protected sites, particularly where the parent stand has been only partially destroyed, reproduction of the tolerant species is more abundant and larch and lodgepole pine reproduction is sparse or completely lacking.

Early development of the established reproduction stand is characterized by rapid growth and dominance of the less tolerant species. Western larch, if present, rapidly outstrips white pine, making about one and one-half times as much height growth as the pine in the first 30 years. Later the white pine gradually gains on the larch, at about 90 years yields only a 10- to 15-percent advantage, and when fully mature approximately equals larch in height. Lodgepole pine, also, outstrips white pine in early height growth, but holds this advantage for only about 50 years. Grand fir growth equals that of white pine. The fact that a large number of suppressed grand firs remain in the stand for many years after similarly suppressed white pines have succumbed often gives the erroneous impression that the white pine has outgrown the grand fir. Douglas-fir lags slightly behind white pine in height growth but is somewhat more aggressive during the early life of the stand, usually making more rapid diameter growth and developing larger and denser crowns.

The more tolerant species, hemlock and redcedar, and to a lesser extent spruce, usually lag in rate of growth and form an understory, but often continue to reproduce for a number of years after the dominant stand has become established. Redcedar makes the slowest early growth, and never achieves dominance in a young stand. Hemlock, while most frequently an understory species in young stands, may form on moist north slopes or under the shade of a residual overstory an important constituent of the dominant reproduction stand, equalling or exceeding the growth rate of white pine. Quite commonly, part of the hemlock is in the dominant stand and the remainder forms a distinct understory. In many stands grand fir, also, performs this dual role of overstory and understory species.

As the stand approaches maturity (pl. 3, *A*) its character slowly changes. The early advantage of larch and lodgepole pine in height growth becomes less conspicuous. Lodgepole pine after 50 years loses ground and is seldom an important component of the stand after 100 years. Douglas-fir, also, usually present but seldom abundant,





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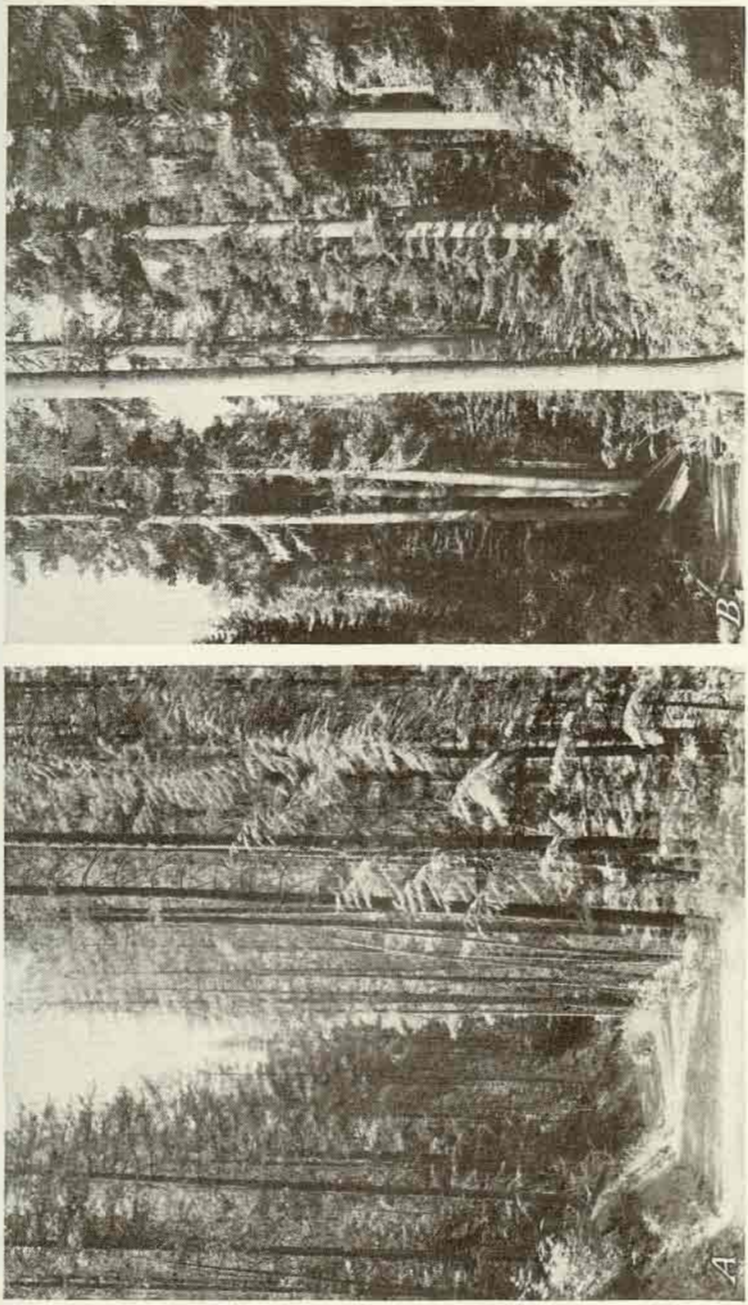
WESTERN WHITE PINE TYPE ON THE DECEPTION CREEK EXPERIMENTAL FOREST, IDAHO.

A, A typical white pine drainage; *B*, dense, nearly pure pine stand 160 years old.

F173284—350898

NATURAL REPRODUCTION IN THE WESTERN WHITE PINE TYPE.

A, Vigorous 35-year-old stand, principally western white pine with admixture of grand fir and Douglas-fir; *B*, western white pine, Douglas-fir, western larch, grand fir, and Engelmann spruce developing under a 90-year-old stand of lodgepole pine and a few western larch veterans.



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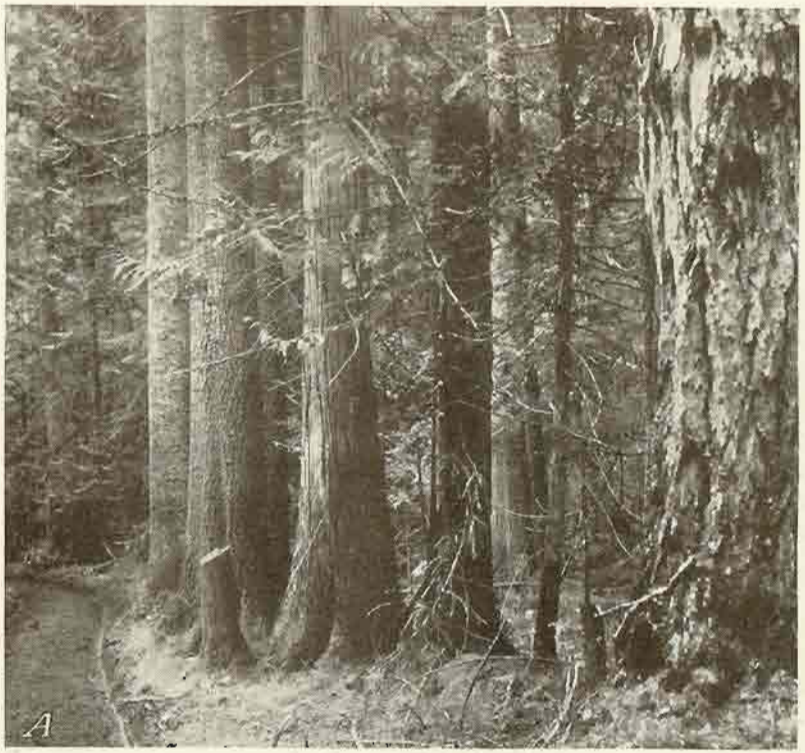
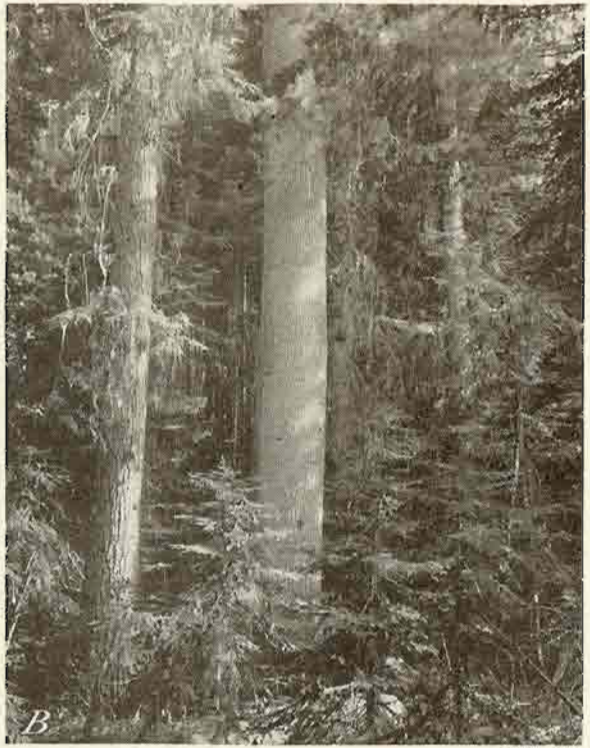
UNDERMATURE AND MATURE STANDS OF WESTERN WHITE PINE.

A, Dense 75-year-old stand of white pine and western larch with understory of hemlock and redcedar; *B*, mature stand.





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THE CLIMAX TYPE.

A, Climax stand of western white pine, western redcedar, and western hemlock; *B*, a veteran white pine in an overmature stand composed principally of grand fir and western hemlock.

fails to keep up sufficiently rapid height growth to maintain its position in the dominant canopy and is not sufficiently tolerant to thrive in an intermediate position. Its susceptibility to attack by fungi, particularly the root rot fungus (*Armillaria mellea*), removes individuals from the stand at a comparatively early age—according to consistent records from permanent sample plots on the better white pine sites this weeding-out process may begin as early as 40 years. As the stand approaches maturity, decay becomes fairly prevalent in hemlock and grand fir, but this is of economic rather than silvicultural importance, as it affects but little the vigor and growth of individual trees.

The tolerant species become increasingly conspicuous as the stand advances in age. Openings resulting from light fires, blowdowns, or insect and disease attacks are largely filled by the more tolerant species, principally grand fir, hemlock, and redcedar, either through development of reproduction already present but hitherto suppressed or through subsequent seeding. The more intolerant species, including white pine, can neither persist in the form of an understory nor start from seed under dense shade.

Maturity of western white pine stands is reached between 140 and 200 years, when white pine and its associates in the dominant stand attain maximum volume (pl. 3, *B*). The stand then enters into a long period of maturity marked by the gradual decline of the less tolerant species and the slow ascendency of the more tolerant. Douglas-fir drops out soon after the stand reaches maturity. Most of the white pine then gradually drops out, accompanied or followed by the larch. Formerly suppressed hemlock, grand fir, and redcedar fill some of the openings, and eventually new reproduction, mostly though not entirely of these very tolerant species, fills other gaps in the stand. There finally results, on the average site, an irregular and uneven-aged forest mainly composed of grand fir, western hemlock, and western redcedar, which is believed to be the climax forest type of the region (pl. 4, *A*). In the northern part of the type's commercial range the climax forests are typically redcedar and hemlock, with little grand fir. In the Clearwater country, to the south, the climax forests are mainly redcedar and grand fir, with little hemlock. Among these species, redcedar is king, attaining at times an age of more than 600 years and a diameter of 10 feet (*39*).

As the climax type is approached, the less tolerant species do not drop out either regularly or completely, but irregularly and slowly, remaining in the stand as scattered trees for a very long time (pl. 4, *B*). Fire, disease, insects, wind, and snow all play a part in the slow march toward the climax, operating in an irregular and haphazard manner that often obscures the successional trend. At almost any stage, partial or complete destruction of the forest may cause a partial or complete repetition of successional development. In fact, few stands ever reach the climax stage; the western white pine type is essentially a transition type of scarcely subclimax stability, perpetuated largely by fire. Most of the few truly climax stands that have been found are limited in area and confined to moist, protected sites.

The life histories of several old stands, as unraveled by Marshall (*46*), showed a very irregular and intricate pattern of age classes.

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Table 2 brings out the complex nature of one such stand. Evidences of fairly distinct 1-, 17-, 90-, 130-, 220-, 280-, 340-, and 400-year age classes were found in this stand, with fire scars corresponding to the dates of origin of all but the two oldest. The ability of the tolerant redcedar and hemlock to reproduce following minor disturbances in the stand is evidenced by the fact that these species are represented in 12 and 11, respectively, of the 18 age classes included in table 2, while the less tolerant white pine, spruce, and alpine fir are found in only 4, 3, and 5 of the age classes, respectively. Even in comparatively young stands, evidence can often be found of one or more visitations of fire. For example, in a 19-acre mixed white pine stand near Orofino, Idaho, of which the youngest tree was 90 years of age and the oldest (other than one 345-year-old veteran) 195 years, Rapraeger (*53*) found unmistakable evidence of 5 separate fires occurring within a span of 70 years.

TABLE 2.—*Age distribution of trees of different species 6 inches d. b. h. and larger in a river-bottom western white pine stand on Granite Creek, Kaniksu National Forest* [1]

Age class (years)	Western white pine	Engelmann spruce	Alpine fir	Western hemlock	Western redcedar	Entire stand
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
61–80	0	0	11	22	12	12
81–100	0	0	0	4	6	3
101–120	0	0	22	4	0	5
121–140	8	0	11	22	6	12
141–160	0	0	0	4	6	3
161–180	0	0	0	4	0	2
181–200	0	0	22	9	6	8
201–220	34	0	34	14	12	19
221–240	0	0	0	0	6	2
241–260	0	33	0	9	6	6
261–280	50	0	0	4	12	14
281–300	0	0	0	0	0	0
301–320	0	0	0	4	6	3
321–340	8	33	0	0	11	6
341–360	0	0	0	0	0	0
361–380	0	0	0	0	0	0
381–400	0	34	0	0	0	2
401+	0	0	0	0	11	3
Total	100	100	100	100	100	100

[1] After Marshall (*46*)

CLIMATIC FACTORS AFFECTING REGENERATION

The western white pine region, despite the great variation in forest composition found within it, is fairly well defined in terms of important climatic conditions. These include a short summer season of scanty precipitation and low humidities with a high percentage of clear, hot, sunny days, and long winters with heavy snowfall and fairly low temperatures. Wind velocities are uniformly low, especially during the growth period. The growing season is roughly the 4-month period from May to August. Phenological observations have shown that growth in the region is largely independent of the length of the frostless season. Observations made on reproduction and immature stands from 1928 to 1934, inclusive, at selected points throughout the region indicate that annual diameter growth begins between the middle of April and the middle of May and ends between the middle of August and the first week in September. Height growth, beginning at some

stations somewhat later, usually ends from three weeks to a month earlier, ending for western white pine by about August 15. Preliminary data indicate that in mature stands growth begins somewhat later and terminates at about the same time.

As would be expected, weather records for this sparsely settled, rough, mountainous region are fragmentary, and are mostly from stations located at the region's lower altitudinal limits or at its boundaries. However, a considerable quantity of applicable data are available, principally from year-long weather stations operated by the Forest Service in cooperation with the Weather Bureau and a few short-time weather stations maintained by the Forest Service.[21] Figure 4 locates these weather stations. A considerable number of them are just outside the borders of the western white pine region, so that the records permit a contrast of conditions within and without the region. Although in many cases records are fragmentary, they furnish considerable information on precipitation and temperature, two most important factors.

Precipitation

Mean annual precipitation in the western white pine region ranges from 28 to nearly 50 inches. It increases markedly with elevation, as might be expected, some of the higher mountain stations showing precipitation means several inches in excess of those shown by nearby valley stations over similar periods. It varies consistently (fig. 5) with geographic location within the region, ranging approximately from 28 to 29 inches in the northern portion to 32 to 49 inches in the Wallace sector and in the southern portion.

A great deal of this precipitation comes in the form of snow. At 13 stations (table 3) within the region's exterior boundaries, snowfall

Table 3.—*Mean annual snowfall at 13 weather stations in the western white pine region in 1912–33, inclusive*

Weather station	Average annual snowfall	Length of record	Weather station	Average annual snowfall	Length of record
	Inches	*Years*		*Inches*	*Years*
Priest River experimental forest	86.6	22	Roland	244.4	6
Sandpoint	75.2	22	Avery	73.1	17
Heron	98.9	12	Kellogg	63.3	19
Trout Creek	100.2	7	Musselshell-Pierce	153.2	7
Haugan	107.9	20	Pete King ranger station	48.0	5
Prichard	58.8	8			
Wallace	95.0	17	Average	102.8	-------
Mullan	131.6	3			

averaged 102.8 inches annually during the period 1912–33, ranging from 48 inches at Pete King, situated at the southern extreme of the region, to 244.4 inches at Roland, situated at the upper altitudinal extreme. At most of these stations snow lasts until about the end of April, and first snow comes about the end of October.

[21] Within and near the western white pine region the Forest Service regularly operates during the summer months more than 90 forest weather stations, principally to measure fire weather and forest inflammability (*14*). Few of these stations, however, have been operated for a sufficient number of years or during a long enough period of the year to provide records that could be used in this discussion.

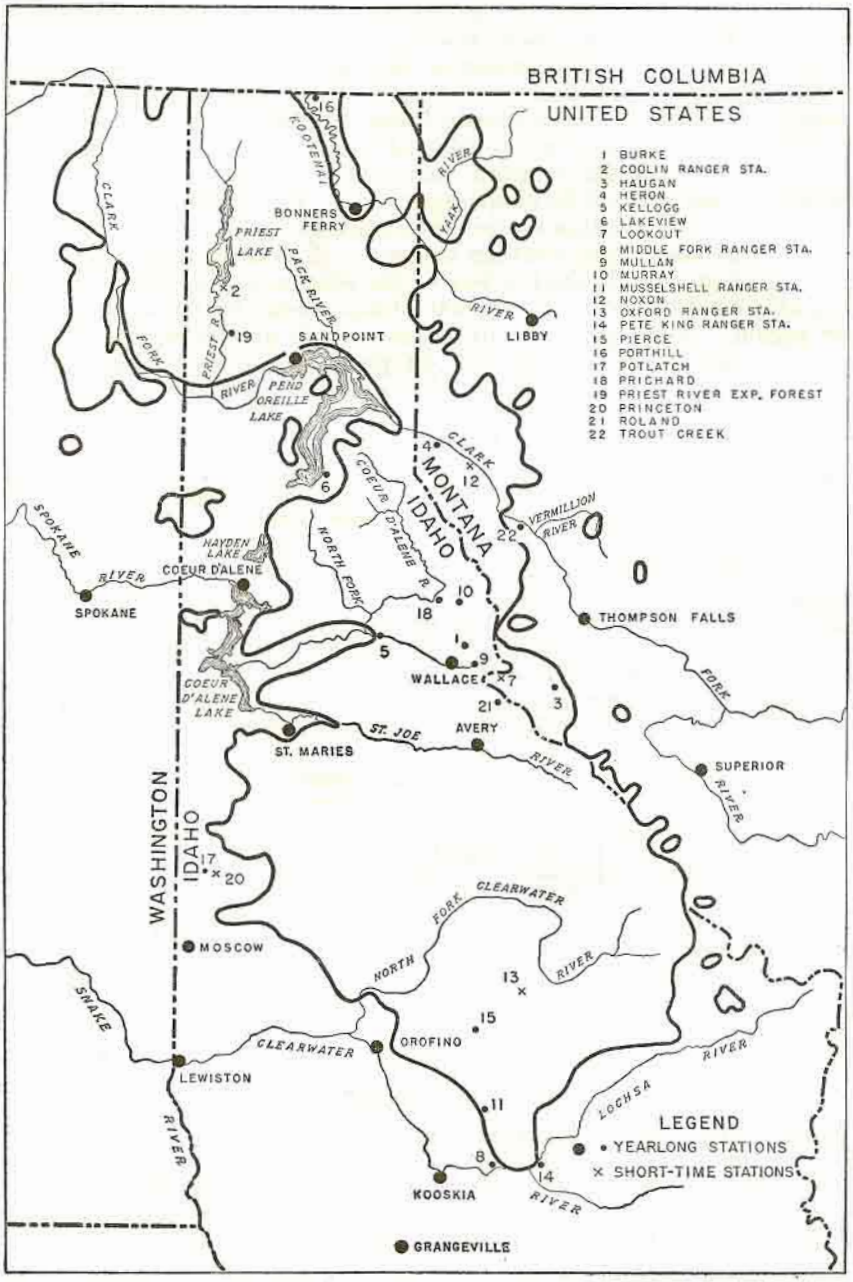

FIGURE 4.—Location of year-long and short-time weather stations in and near the western white pine region.

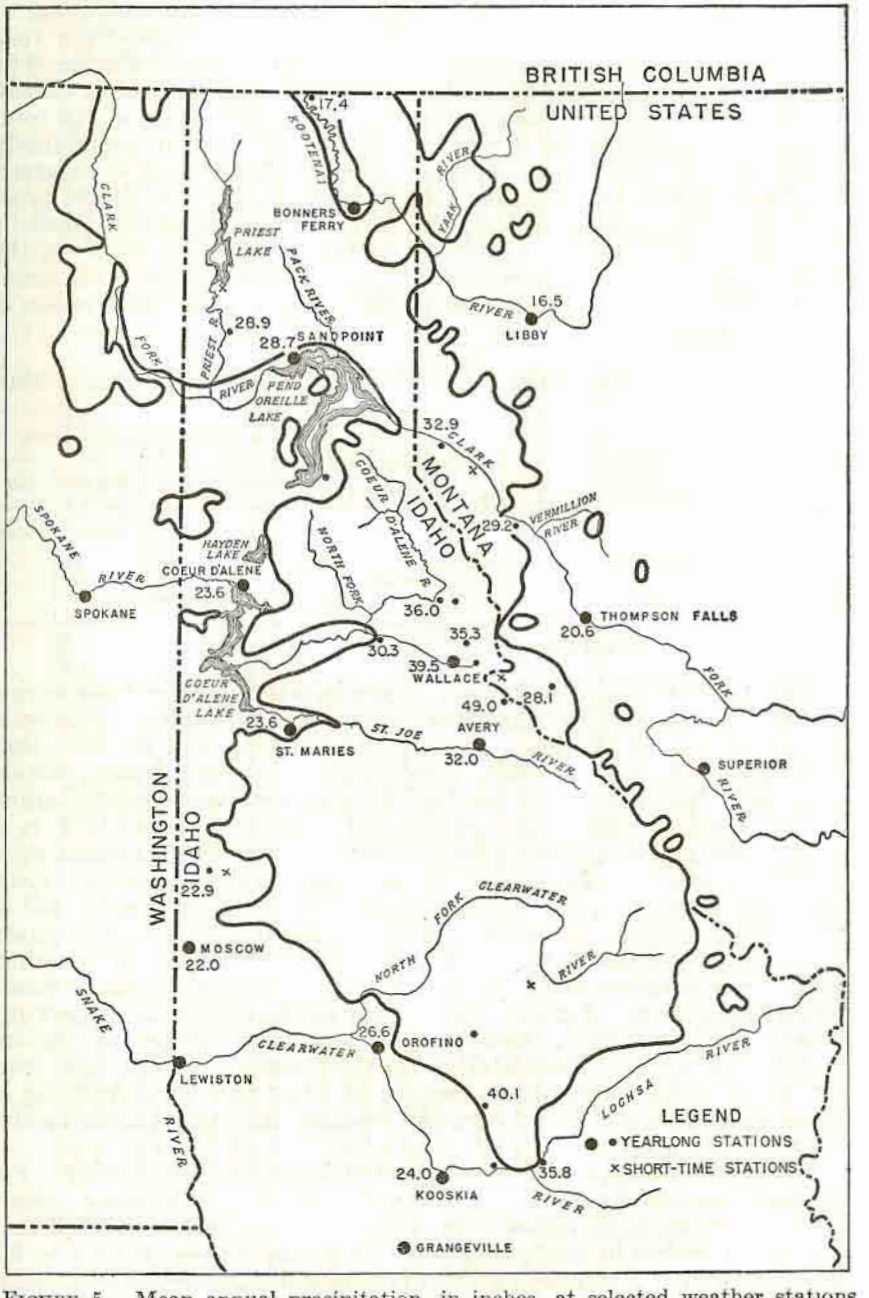

FIGURE 5.—Mean annual precipitation, in inches, at selected weather stations in and near the western white pine region.

Approximately 35 percent of the region's total annual precipitation falls in the winter months and 50 percent, almost equally divided, in spring and fall (table 4). In summer, about half the remaining 15 percent falls in June, and the months of July and August are very dry. Precipitation in this region is classified as a sub-Pacific type (*29*), being distinguished from the Pacific type, which it most closely resembles, by the fact that a proportionately smaller part of the total annual precipitation takes place in the winter and proportionately larger parts in the spring and fall. The sub-Pacific type is regarded by climatologists as a transition stage between the true Pacific type, with the precipitation peak in the winter, and the eastern foothills and plains, or Missouri types (*62*), with precipitation peaks in the spring and summer, respectively. The generally consistent character of the precipitation distribution in the western white pine region is shown in figure 6.

TABLE 4.—*Seasonal distribution of precipitation in the northwestern United States*

Station or region	Precipitation type [1]	Total mean annual precipitation			
		Winter	Spring	Summer	Fall
		Percent	*Percent*	*Percent*	*Percent*
Seattle, Wash.	Pacific	42	20	8	30
Western white pine region (11 stations)	Sub-Pacific	35	24	14	27
Helena, Mont.	Eastern foothills	15	33	30	22
Miles City, Mont.	Plains	11	32	40	17

[1] As defined by Ward (*62*) and Kincer (*29*).

The quantity and distribution of precipitation, particularly during the growing season, is important in natural regeneration in several ways. Owing to the heavy winter precipitation and the fact that sub-soils in the western white pine region are usually moist, mature trees are frequently independent of growing-season precipitation. Young seedlings, however, particularly during the critical 2 to 3 years immediately following germination, are largely dependent upon current rainfall. Unless favorable moisture conditions prevail during the early portion of the growing season, seedlings frequently fail to root deeply enough to obtain sufficient moisture later in the season for survival. Table 5 shows the mean monthly and total growing-season precipitation at 13 stations scattered throughout the western white pine region. Figure 7 shows geographically the mean growing-season precipitation at these stations and at a number of stations outside the region. Precipitation for the growing season ranges from 5.1 to 7.1 inches and occurs mostly in May and June, ranging in these months from 3.6 to 5.3 inches, whereas July and August receive only 1.2 to 2.1 inches.

Growing-season precipitation is very irregular in quantity. For example, at the Priest River Experimental Forest weather station seasonal totals have varied from a high of 10.1 inches in 1912 to a low of 2.1 inches in 1922; at Avery, from 13.7 inches in 1915 to 2.6 inches in 1931. Extended periods of extreme drought occur frequently. Records of summer drought periods from 1912 to 1931 at the Priest River Experimental Forest (table 6), an area typical of the western white pine habitat, give the number of days without measurable

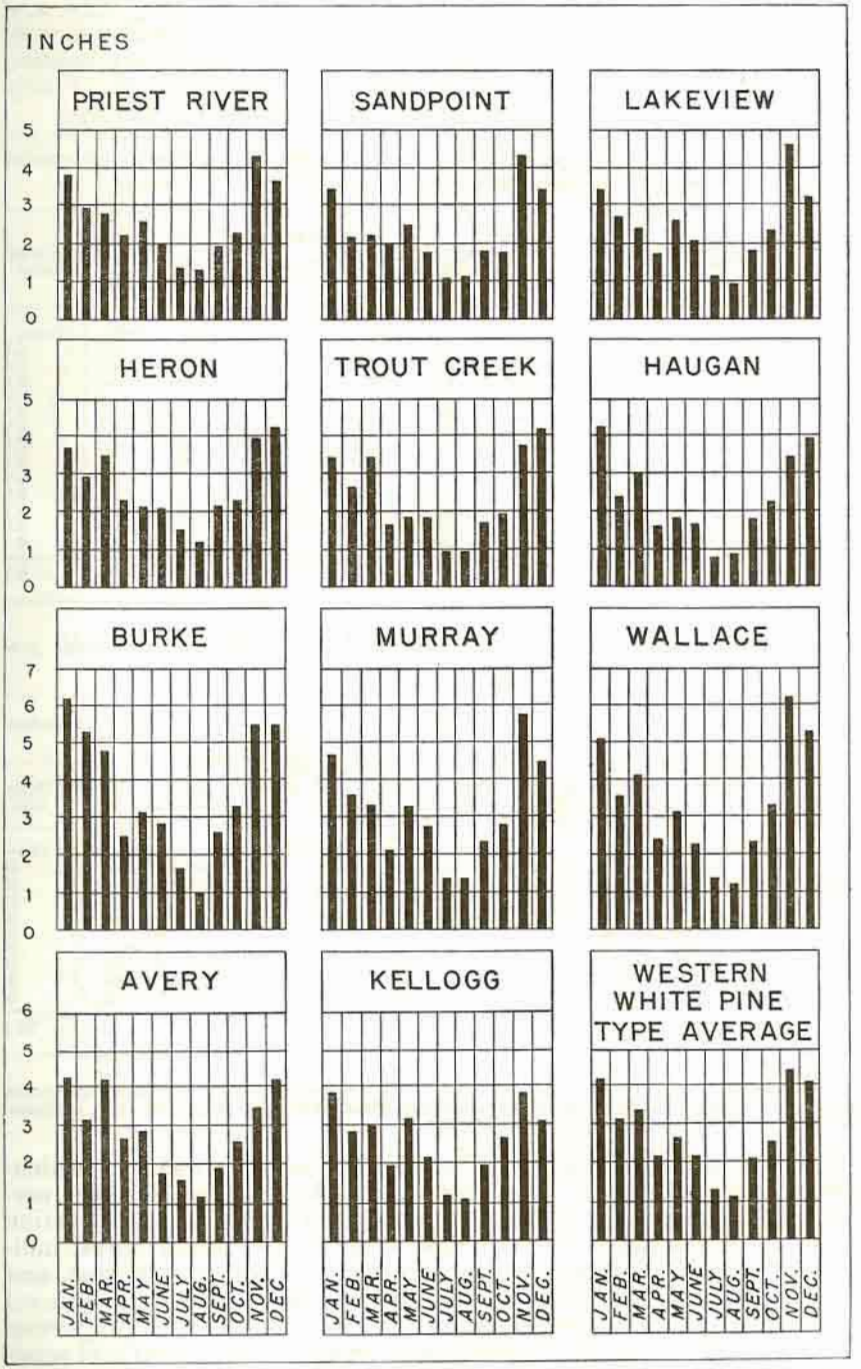

FIGURE 6.—Monthly distribution of precipitation in the western white pine region.

precipitation (i. e., with less than 0.01 inch) during June, July, and August as ranging from 53 to 80 out of a possible 92. Similar records for the 183-day period of April through September at the same station give an average of 130 days without measurable precipitation. Yearly maximum periods of unbroken drought ranged from 9 to 43 days.

TABLE 5.—*Mean monthly precipitation during the growing season at 13 weather stations in the western white pine region in 1912–33, inclusive*

Weather station	Length of record	Mean precipitation				Growing season
		May	June	July	August	
	Years	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
Priest River experimental forest	22	2.0	1.8	0.8	1.1	5.7
Sandpoint	22	1.9	1.7	.7	1.1	5.4
Heron	21	2.1	1.9	1.0	1.1	6.1
Trout Creek	20	2.0	1.8	.8	.8	5.4
Haugan	22	1.8	1.8	.7	.8	5.1
Prichard	15	2.6	1.9	.7	.9	6.1
Wallace	21	2.7	2.3	.9	1.2	7.1
Mullan	8	2.9	2.3	.6	.7	6.5
Roland	8	2.7	2.1	.7	1.0	6.5
Avery	19	2.3	2.0	.9	1.0	6.2
Kellogg	22	2.4	2.0	1.0	1.1	6.5
Musselshell-Pierce	13	3.1	2.2	1.0	.7	7.0
Pete King ranger station	11	2.8	2.5	.4	.8	6.5
Average	17	2.4	2.0	.8	1.0	6.2

TABLE 6.—*Number of days in June, July, and August without measurable precipitation* [1] *at the Priest River Experimental Forest* [2]

Year	Days without measurable precipitation	Longest period of unbroken drought			Year	Days without measurable precipitation	Longest period of unbroken drought		
		Beginning date	Ending date	Duration			Beginning date	Ending date	Duration
	Number			*Days*		*Number*			*Days*
1912	53	June 16	June 26	11	1923	64	July 18	July 31	14
1913	61	Aug. 18	Aug. 28	11	1924	69	July 23	Aug. 3	22
1914	71	July 15	Aug. 5	22	1925	78	July 23	Aug. 13	21
1915	58	Aug. 8	Aug. 16	9	1926	75	July 14	Aug. 15	33
1916	64	July 23	Aug. 7	16	1927	65	July 6	July 24	19
1917	77	July 1	July 29	29	1928	66	Aug. 3	Aug. 23	21
1918	65	June 1	June 16	16	1929	73	July 8	July 31	24
1919	77	June 28	July 23	26	1930	77	July 11	Aug. 8	29
1920	75	July 14	Aug. 8	26	1931	80	July 31	Aug. 31	32
1921	80	July 3	Aug. 14	43					
1922	80	July 11	Aug. 9	30	Average	70.4			22.2

[1] I. e., with less than 0.01 inch.
[2] Data from Jemison, G. M., CLIMATOLOGICAL SUMMARY FOR THE PRIEST RIVER FOREST EXPERIMENT STATION 1912–31, table 17. Northern Rocky Mountain Forest and Range Expt. Sta. (n. d.) [Mimeographed.]

Hazardous conditions for the survival of young seedlings, particularly in dry seasons, are intensified during the summer by a high percentage of clear, sunny days with low humidities and high evaporation rates. Records taken at the Priest River Experimental Forest indicate an average of about 20 clear days each in July and August, and Kincer (*30*) points out that during the summer months this general region receives 60 to 80 percent of possible sunshine—a proportion exceeded nowhere in the United States except in the desert and semidesert portions of Oregon, Nevada, Arizona, and interior California. Not only does clear weather aid in reducing soil moisture, but on ex-

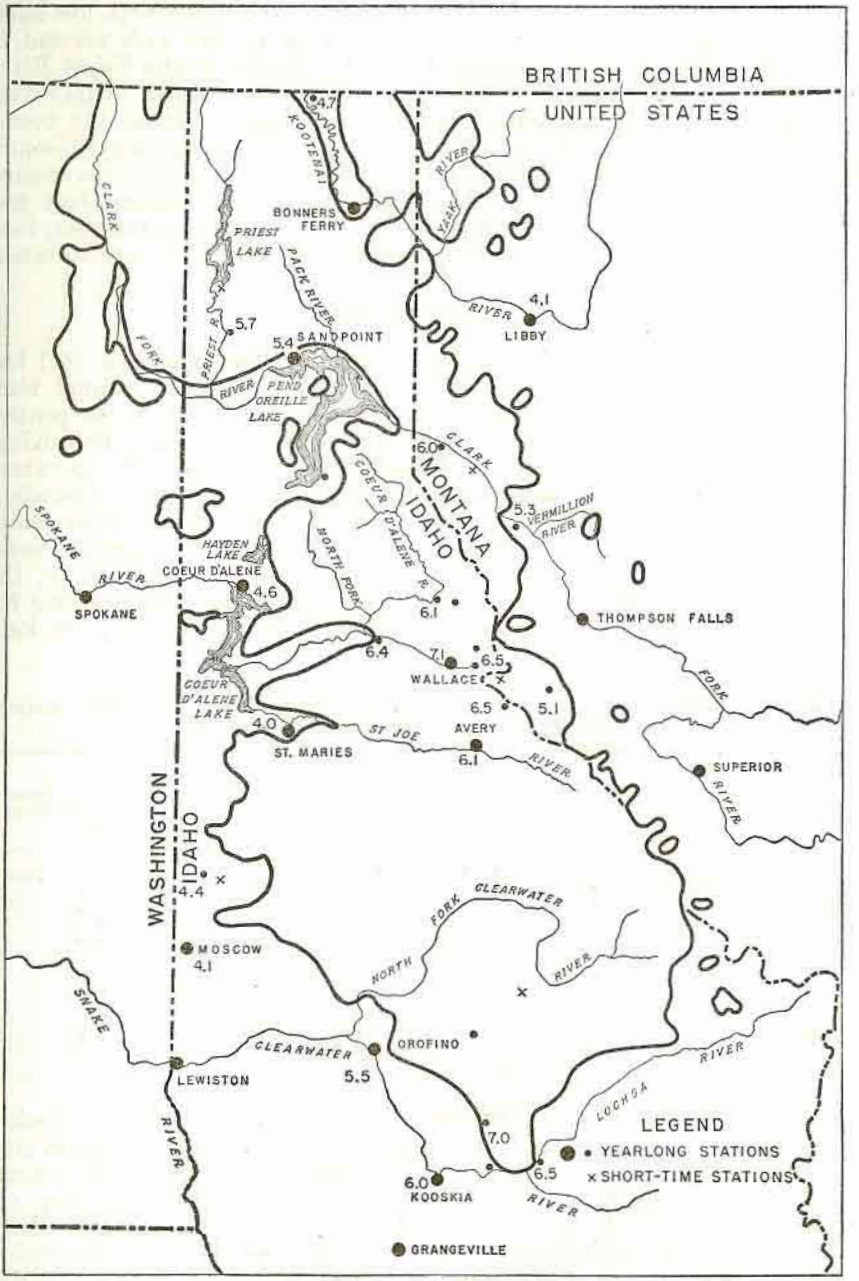

FIGURE 7.—Mean growing-season (May-August) precipitation, in inches, at selected stations in and near the western white pine region.

posed sites where moisture content of the topsoil is low it produces very high surface-soil temperatures, which severely injure or kill young plants by causing lesions at the ground line. Coupled with low summer humidities (averaging 37.1 percent in July and 41.9 percent in August and frequently dropping below 15 percent at the Priest River Experimental Forest), the many clear days also induce evaporation rates so high that transpiration becomes a heavy tax on the young seedlings. Fortunately, as has been remarked, these severe conditions are to some extent balanced by the low wind velocities (averaging less than 2 miles per hour 8 feet above the ground during July and August at the Priest River Forest), heavy winter precipitation, long retention of snow cover at many points, and moderate precipitation during May and June.

Temperature

The western white pine region occurs in what Merriam (*48*) has defined as the Canadian temperature zone. Average annual temperature means (fig. 8) range from 41.7° F. at Roland, in the central part of the region at an elevation of 4,150 feet to 50° F. at Pete King, on the southern border at an elevation of 1,550 feet. Temperature increases toward the south and as elevation decreases. Growing-season temperatures for 11 weather stations in the western white pine region are summarized in table 7. The rise in monthly mean temperature is abrupt from May and June, culminating in July, the warmest month of the year. Mean growing-season temperatures for the stations listed range from 56.8° F. at Roland to 65.9° F. at Pete King.

Table 7.—*Monthly mean temperatures for the growing season at 11 weather stations in the western white pine region in 1912–33, inclusive*

Weather station	Monthly mean temperature					Length of record
	May	June	July	August	Average	
	° F.	*° F.*	*° F.*	*° F.*	*° F.*	*Years*
Priest River experimental forest	50.7	57.9	63.8	62.6	58.8	22
Sandpoint	52.7	59.3	65.2	63.9	60.3	22
Heron	51.9	58.4	64.6	63.4	59.6	21
Trout Creek	50.9	57.7	63.6	61.9	58.5	15
Haugan	50.0	57.4	62.5	61.0	57.7	22
Wallace	52.6	59.9	66.5	65.6	61.2	21
Mullan	50.0	57.4	63.9	63.9	58.8	6
Roland	47.4	55.1	62.5	62.0	56.8	7
Avery	53.0	60.0	66.9	65.5	61.4	19
Kellogg	53.5	60.7	67.3	65.8	61.8	22
Pete King ranger station	57.2	63.9	71.7	70.9	65.9	9

Although seasonal or annual temperatures at any particular weather station are relatively stable from year to year, temperature differences between even nearby stations are often large as a result of elevational and other topographic differences, particularly those affecting air drainage. As with most mountain climates, seasonal and daily fluctuations are marked (*30*). For eight selected stations in the white pine region, average daily range of temperatures in January varies from 12° to 19° F. and from 34° to 42° F. in July and August. The monthly averages of daily maxima for these stations reach peaks of 82° to 87° F. in July, and those of the minima reach lows of 12° to

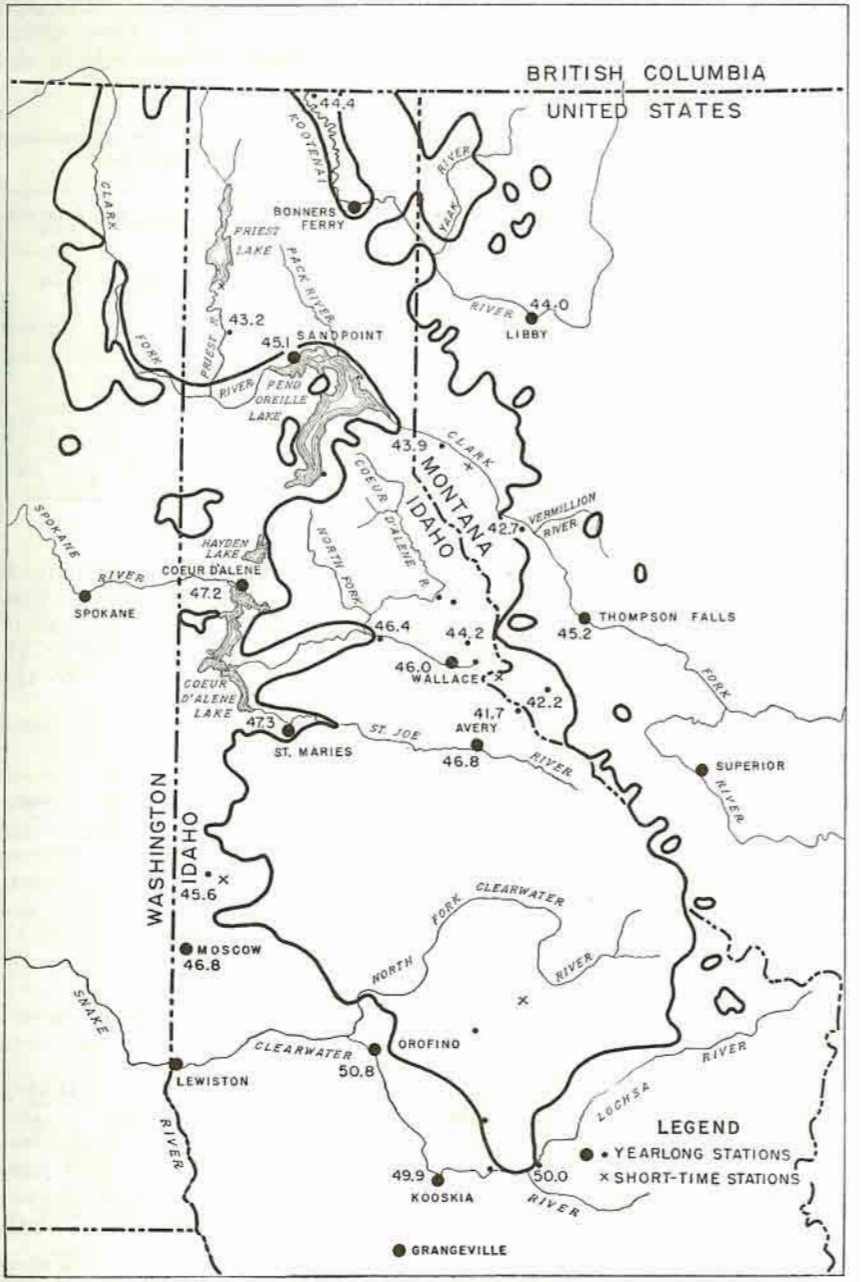

FIGURE 8.—Mean annual temperature, in degrees Fahrenheit, at 20 weather stations in and near the western white pine region.

22°, usually in January, the total annual range amounting to 62° to 71°. Rather wide deviations above and below the average range are fairly common. Table 8 summarizes the average yearly absolute maximum and minimum temperatures recorded at 12 western white pine stations for 1912–33. Subzero temperatures are the rule in the winter, and maxima around 100° F. in the summer.

TABLE 8.—*Yearly mean absolute maximum and minimum temperatures at 12 weather stations in the western white pine region in 1912–33, inclusive*

Weather station	Maximum	Minimum	Length of record [1]
	°F.	*°F.*	*Years*
Priest River experimental forest	97.3	−18.8	22
Sandpoint	97.4	−14.0	22
Heron	100.6	−15.0	19–20
Trout Creek	100.9	−20.4	14
Haugan	98.2	−27.9	21
Wallace	99.8	−7.8	21
Mullan	98.0	−14.3	6
Roland	93.0	−14.4	7
Avery	102.5	−7.8	19–20
Kellogg	101.9	−11.5	22
Musselshell-Pierce	99.8	−27.0	6–3
Pete King ranger station	107.0	−3.0	10–9

[1] Where 2 figures are given first figure is for maxima, second for minima.

These wide fluctuations have a very important effect on natural regeneration. In combination with low to moderate mean temperatures, they indicate frequent frosts, which are an active cause of seedling mortality. The frostless season is very short (table 9), ranging commonly from about 60 to 160 days, and owing to the

TABLE 9.—*Average length of frostless season at 13 weather stations in the western white pine region in 1912–33, inclusive*

Weather station	Frostless season	Length of record	Weather station	Frostless season	Length of r cord
	Days	*Years*		*Days*	*Years*
Priest River experimental forest	62	20	Mullan	103	8
Sandpoint	116	21	Roland	105	8
Heron	(1)	22	Avery	108	17
Trout Creek	(1)	20	Kellog	129	21
Hougan	(1)	22	Musselshell-Pierce	71	11
Prichard	105	3	Pete King ranger station	159	10
Wallace	140	19			

[1] Record often reads merely "Frost every month."

erratic character of the deviations below the normal minima it is very irregular from year to year. Frosts may occur in any month. The occurrence of below-freezing temperatures is increased by the frequency of temperature inversions, i. e., the occurrence of lower temperatures at low elevations than at high owing to the drainage of cold air to the lower elevations, a phenomenon recorded in the western

white pine region by Larsen (*36*) and Gisborne.[22] Minimum temperatures at a given low elevation may be as much as 10° F. lower than at nearby high elevations. Cold-air pockets created in this way are often marked ecologically by the occurrence of subalpine species such as alpine fir and Engelmann spruce along stream bottoms and flats. In such locations frost may prove an active agent in seedling damage and mortality.

Although heavy frost damage to native tree species is usually limited to young seedlings, sudden drops in temperature occasionally cause appreciable widespread damage even to mature trees. On December 15, 1924, for example, a drop in temperature from 45° to −12° F. in 20 hours resulted in extensive killing or browning of needles over a large forested area in Washington, Idaho, Montana, and British Columbia. Again in 1935 a drop in the daily temperature minimum from 23° on October 27 to −12° on October 31, as observed at the Savenac Nursery at Haugan, Mont., resulted in widespread killing of foliage. Western white pine was especially hard hit; in some 20-year-old white pine plantations near the Savenac Nursery nearly every tree turned brown. Practically all of these trees subsequently recovered, the actual mortality being less than 5 percent.

Climatic Controls on Range

The geographic boundaries of the western white pine region are fairly well defined in terms of climatic factors. According to Larsen (*40*), extension of the type is limited at the lower elevations by deficient moisture and at the upper elevations by unfavorable temperatures. The precipitation values given in figures 5 and 7, however, show clearly that the southern boundary of the type, which does not coincide with any definite change in elevation, is not fixed by insufficient precipitation alone. Some stations south of the boundary receive as much precipitation as stations at similar elevations within it.[23] The stations to the south, however, have higher temperatures. Numerous investigators have pointed out that the effectiveness of precipitation depends to a material extent on the balance between precipitation and evaporation, usually expressed as the P/E ratio.

Lack of evaporation records prevents direct computation of this value here, but Thornthwaite (*58*) has recently suggested a method permitting the substitution of temperature for evaporation data. Effectiveness indices for both annual and growing-season precipitation means have been computed in this way for a number of stations within and near the borders of the western white pine region, and are presented in figures 9 and 10. These values show that owing to higher temperatures to the south, higher precipitation there is less effective than precipitation occurring within the type's range. The precipitation-effectiveness index for climatic conditions favorable to the development of western white pine stands appears to be about 110 for the year or 11.5 for the growing season.

[22] Gisborne, H. T., Paired minimum temperatures as indices of fair or foul weather. North-Rocky Mountain Forest and Range Expt. Sta. Appl. Forestry Note 65. 1934. [Mimeographed.]

[23] Leiberg (*42*) cites evidence indicating a former wider distribution of western white pine to the south.

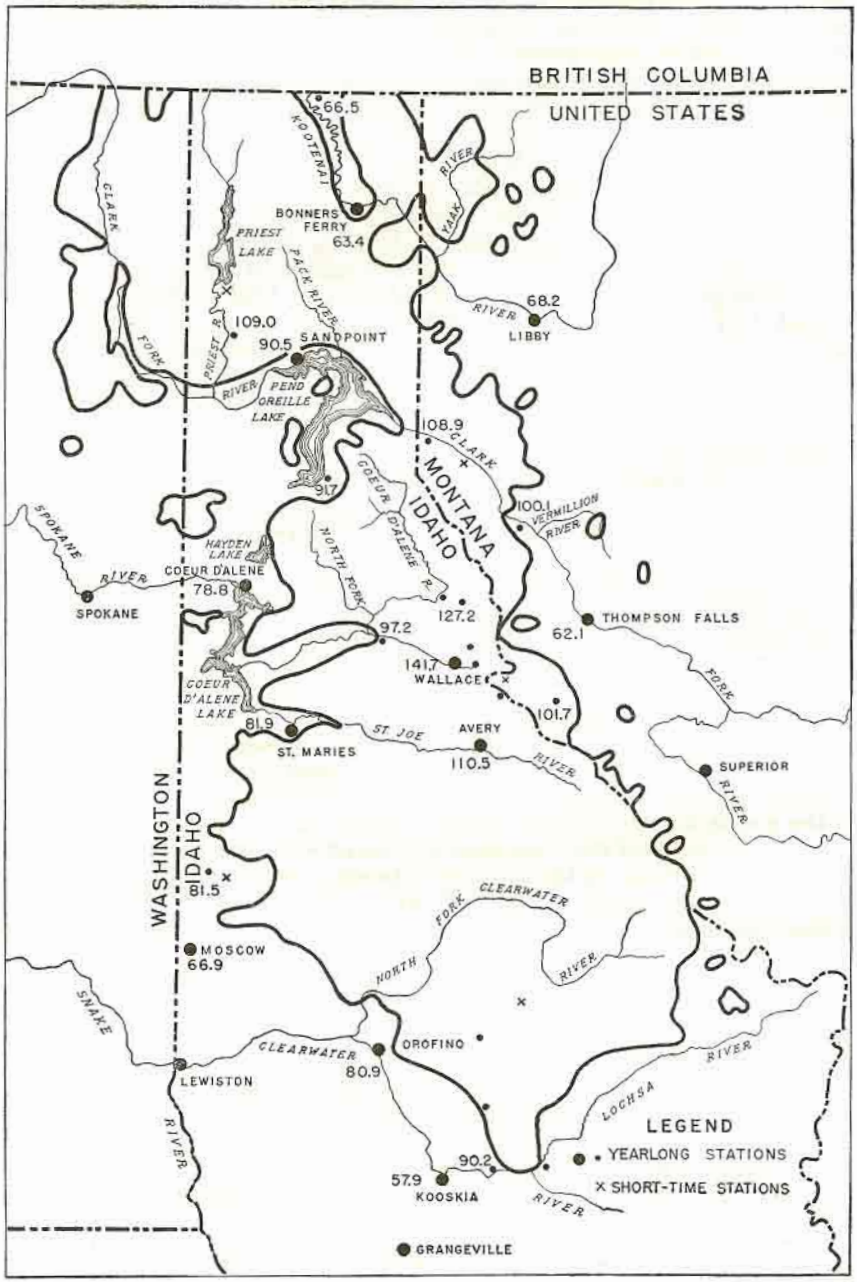

FIGURE 9.—Annual precipitation-effectiveness indices for selected stations in and near the western white pine region, based on annual means of precipitation and temperature.

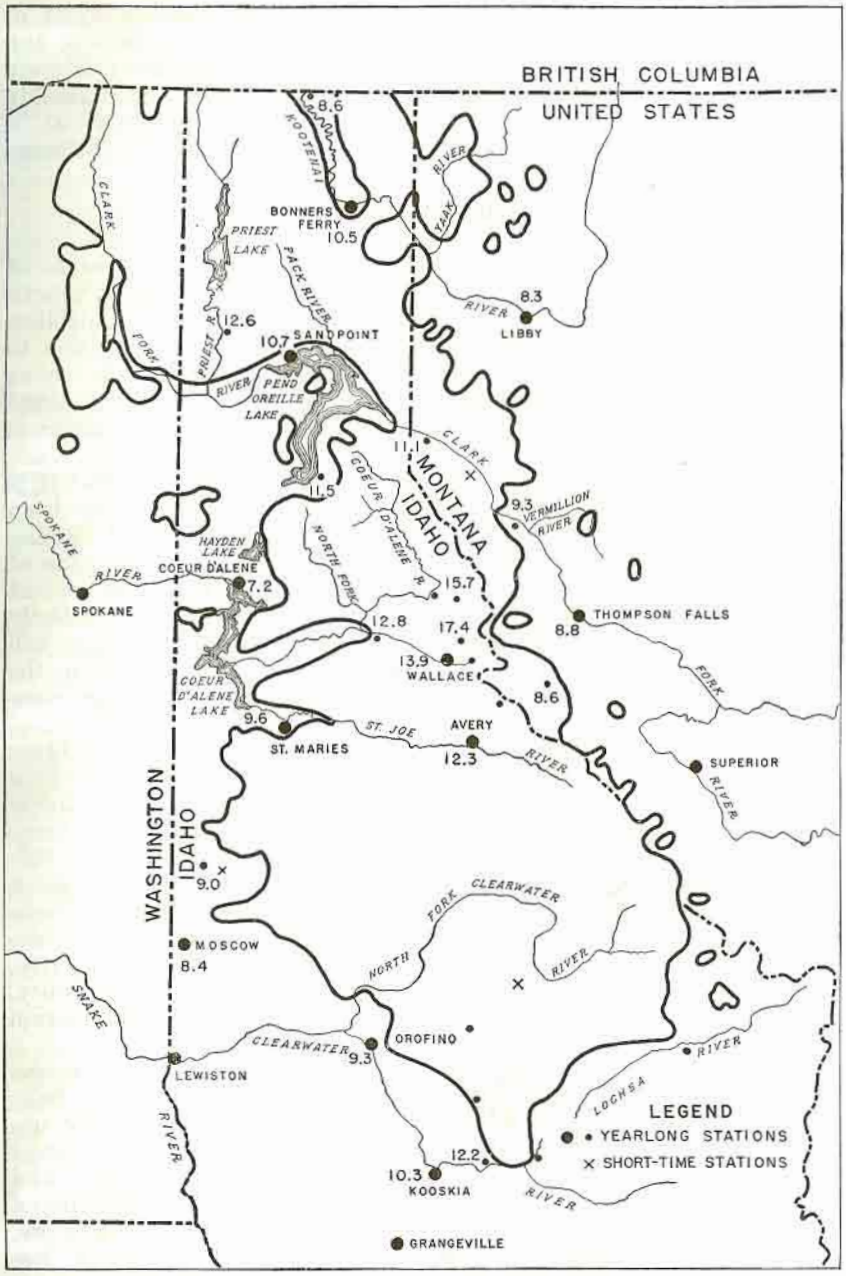

FIGURE 10.—Growing-season precipitation-effectiveness indices for selected stations in and near the western white pine region, based on mean growing-season (May–August) precipitation and temperature.

SUSCEPTIBILITY TO INJURY

Fire, disease, and insects are the major agencies causing injury or destruction of western white pine stands. Wind, snow, animals, and occasionally drought and sudden drops in temperature are relatively minor causes. Silvicultural consequence of injuries has been already touched upon in connection with the successional development of natural stands and climate; the purpose here is to describe the more important agencies.

Fire Damage

Fire is the most characteristic, active, and omnipresent cause of injury to western white pine stands and has left its mark on practically every acre of forest land in the region. The type's susceptibility to fire is notorious. Fire also makes an important contribution to the incidence and spread of disease and insect attacks. It colors every phase of management practice; regeneration methods, stand improvement, and slash-disposal methods must often be modified to avoid undue conflict with fire-control requirements.

The influence of fire on forest succession and the fact that it is largely responsible for perpetuating the type have already been brought out. Successful application of most methods of cutting intended to obtain natural reproduction necessitates extensive use of fire to dispose of slash and other debris. Fire also has important physical and chemical effects on the soil—at present imperfectly understood—that affect natural regeneration. Discussion here will be limited to a few of the outstanding characteristics of fire in the region, and the relative fire resistance of the different species associated in the type.

Fires are unusually destructive in the western white pine type; often they kill all trees over extensive areas—particularly in cut-over and partially burned stands where the opening up of the forest canopy has permitted thorough drying of a large volume of fuels. Once started in such a stand, fire often gets beyond control, causes 100-percent loss, and spreads with disastrous results to adjoining uncut timber that might otherwise have been protected successfully. Extensive logging in the type has intensified both the hazard and the destructiveness of fire. In uncut stands the damage varies in severity, according to such conditions as fuel moisture, volume of fuel, humidity, wind, season of year, and time of day. Fire easily kills reproduction and pole stands of any species.

Many fires, as brought out later in the discussion of forest succession, result in only a partial killing of the stand. These burns have several important results, all economically and silviculturally undesirable. Too often a light fire, by increasing the volume of forest fuels, paves the way for a more destructive fire; spread of insects and disease in the stand also is encouraged by the large quantities of favorable host material provided by fire-injured trees. Furthermore, partial burns encourage reproduction of the more tolerant, less valuable species. Thus fire, while largely responsible for the perpetuation of the western white pine type and often a beneficial agent in the initial establishment of white pine stands, is an entirely un-

TABLE 10.—*Relative fire resistance of individual species in the western white pine type,*[1] *in terms of characteristics affecting fire resistance*

Species	Bark thickness of old trees	Resin in old bark	Root habit	Branching habit
Western larch	Very thick	Very little	Deep	High and very open.
Ponderosa pine	do	Abundant	do	Moderately high and open.
Douglas-fir	do	Moderate	do	Moderately low and dense.
Grand fir	Thick	Very little	Shallow	Low and dense.
Lodgepole pine	Very thin	Abundant	Deep	Moderately high and open.
Western white pine	Medium	do	Medium	High and dense.
Western redcedar	Thin	Very little	Shallow	Moderately low and dense.
Engelmann spruce	do	Moderate	do	Low and dense.
Western hemlock	Medium	Very little	do	Do.
Alpine fir	Very thin	Moderate	do	Very low and dense.

Species	Stand habit	Relative inflammability of foliage	Lichen growth	Relative fire resistance
Western larch	Open	Low	Medium-heavy	Most resistant.
Ponderosa pine	do	Medium	Medium to light	Very resistant.
Douglas-fir	Moderate to dense	High	Heavy to medium	Do.
Grand fir	Dense	do	Heavy	Medium.
Lodgepole pine	Open	Medium	Light	Do.
Western white pine	Dense	do	Heavy	Do.
Western redcedar	do	High	do	Do.
Engelmann spruce	do	Medium	do	Low.
Western hemlock	do	High	do	Do.
Alpine fir	Moderate to dense	do	Medium to heavy	Very low.

[1] After Flint (*12*).

desirable factor in the silvicultural management of stands once established.

Fundamentally, the prevalence of fire in the western white pine type is due to the combination of a summer season characterized by scanty rainfall, many hot, sunny days, frequent low humidities, and occasional hard winds, and a dense forest furnishing a plentiful fuel supply. Contributing causes include dry lightning, fire-detection difficulties, a sometimes inadequate fire-control organization, and the difficulty of quickly transporting sufficient men and supplies to many of the more remote parts of the region. Lightning, in addition to starting approximately 70 percent of all fires in the region, causes dangerous peak loads in fire control. In 1926, for example, lightning started 109 fires on July 12, and 37 more on July 13, on an area of about 700,000 acres on the Kaniksu National Forest. Efforts to cope with the region's fire problem, details of the fire organization, annual losses and costs, and fire behavior are treated elsewhere[24] (*14*) and will not be discussed here.

Resistance of individual species to fire determines their relative ability to survive as components of the type. Little actual study has, however, been made of this subject, largely because the hot fires common to the region erase all evidence of such differences. Most of the available information has been summarized by Flint (*12*), and the following is drawn largely from his report.

Resistance of a given species to fire depends upon a combination of tree characteristics, principally bark thickness, branching habit,

[24] HORNBY, L. G. FIRE-CONTROL PLANNING IN THE NORTHERN ROCKY MOUNTAIN REGION. Northern Rocky Mountain Forest and Range Expt. Sta. 1936. [Multilithographed.]
GISBORNE, H. T., and HORNBY, L. G. FOREST-FIRE CONTROL OBJECTIVES. Northern Rocky Mountain Forest Range Expt. Sta. 1931. [Unpublished.]
U. S. FOREST SERVICE, REGION ONE. FIRE-CONTROL HANDBOOK. Parts I and II. 1936. [Mimeographed.]

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stand habit (density, duff accumulation, etc.), inflammability of foliage, and lichen growth. It is markedly influenced by habitat. For example, grand fir growing in a moist creek bottom succumbs very readily to a creeping ground fire, but on the dry hillsides of the Clearwater River drainage, in Idaho, this tree resists fire better than white pine and nearly as well as Douglas-fir. The difference is due in part at least to thicker bark, deeper root system, and more open stand conditions. Table 10 gives the relative fire resistance of the important species in the western white pine type. Obviously, any such scale of fire resistance must be applied with reservations.

Western larch when mature is by far the most fire-resistant species in the type. Unusually thick bark near the ground, low resin content of bark, deep roots, high and open branching habit, generally open nature of the stand, at least in the immediate vicinity of larch trees, low inflammability of the foliage, and the scanty accumulation of duff beneath larch trees all contribute to a remarkable ability to survive fire. At the other end of the scale is alpine fir, highly susceptible to fire because of its very thin and moderately resinous bark, shallow roots, dense and very low branches with highly inflammable foliage, and medium to heavy lichen growth. The two lichens most important in their effect on fire hazard are black moss or "squaw hair moss" (*Alectoria fremontii*) and green moss or "gray moss" (*A. sarmentosa*). These grow on trees in long festoons or streamers and when dry are almost unbelievably inflammable.

Disease

Some of the most difficult and troublesome management problems in the western white pine type are directly caused by forest-tree diseases. The problem of low-value species is in part due to the prevalence of wood-rooting fungi, which seriously reduce the sound-wood volume of the product. A good share of the heavy protection costs in western white pine forests is spent on disease control. For a pathological treatment of the subject of forest diseases in the type the reader is referred to available literature (*24, 25, 63, 64, 65, 66, 67*). The purpose here is to bring out the silvicultural consequences of the major forest tree diseases found in the type.

WHITE PINE BLISTER RUST

An outstanding menace to the western white pine type is the white pine blister rust, caused by the fungus *Cronartium ribicola* Fischer, which threatens the very existence of white pine as a commercially important component of the type. This disease has proved as serious in western white pine as in any other of the important white pine species of the world.

The white pine blister rust spread into the western white pine region from the Pacific Northwest, where it was accidentally introduced in 1910 on pine seedlings shipped from France to Vancouver, B. C. A survey of the western white pine forests in 1936 by the Bureau of Entomology and Plant Quarantine showed that it occurred on white pine throughout the commercial range of the species. Infection was heaviest on and near the St. Joe and Clearwater National Forests, where approximately 4 percent of all young white pine trees were visibly infected. In other parts of the region, the infected young

trees averaged 1 percent or less. A similar survey in 1937 showed 13 percent of the young pines on the St. Joe forest to be visibly infected. In the vicinity of the older infection centers numerous larger trees are known to be infected, but no specific infection surveys have been made for trees of merchantable size.

Seedlings and saplings are much more quickly killed by the rust than are older trees. In fact, the real threat is to young stands; present merchantable stands can and probably will be harvested before they are materially damaged. The rust works slowly and seldom spectacularly, and for this reason the true gravity of the situation may be underestimated.

Control of *Cronartium ribicola* is made possible by the fact that it is heteroecious; that is, it requires an alternate host to complete its life cycle. Its alternate hosts are members of the genus *Ribes*, popularly known as ribes or as currants and gooseberries. Spores of the organism are carried from one host to the other by the wind. Infection may spread from pine to ribes over distances of as much as 150 miles, but seldom spreads from ribes to pine over a distance exceeding 1,000 feet. Eradication of ribes within and adjacent to stands of white pine consequently prevents infection of the pine.

An extensive program for the control of white pine blister rust in the western white pine region has been under way since 1923. This program is designed to control the rust upon approximately 2,700,000 acres of white pine forest. By March 1939, approximately 2,670,405 acres of land had been covered by the ribes-eradication crews, this total including first, second, and third workings. Results thus far indicate that approximately half the area worked once will require no further ribes eradication until it is further disturbed by either logging or burning. The other half will require a second working in 3 to 5 years after the first. A few areas—principally stream bottoms, where grow the heaviest concentrations of ribes of the most susceptible species—will require a third or even a fourth working. The control program is being prosecuted as vigorously as available funds permit, by the Forest Service, the Bureau of Entomology and Plant Quarantine, and the State of Idaho. Rapid completion of the second working on certain portions of the area and completion of the initial working on the entire area is necessary to protect the heavy investment already made in eradication and to prevent further intensification of the disease. At present, infection is progressing faster than control.

Blister rust cannot be controlled by silvicultural practices, but its control can be aided or impeded by silvicultural practices through their effects on the ecology of ribes. In general, environmental conditions favoring conifer reproduction also favor ribes reproduction, and only within rather narrow limits can one be encouraged or repressed without a like effect on the other.

Ribes seed is extensively stored in the duff of the forest floor in close proximity to mineral soil and maintains its viability for very long periods—possibly even through a forest rotation of 100 to 200 years, though this has not been definitely proved. Following opening up of the forest by logging or fire and consequent disturbance of the duff cover, ribes seedlings often appear in abundance, even on areas practically free of ribes. Short of a hard burn that completely destroys the organic mantle of the soil and with it all stored seed, as a general rule the more disturbance the more ribes. This circumstance

greatly adds to the difficulty of ribes eradication. Destruction today of every single living ribes bush would not end the control problem; new seedlings from seed now in the duff would appear for many years to come after each forest disturbance by cutting or fire.

Ribes, like conifers, germinate best on freshly exposed mineral surfaces and poorest on undisturbed duff surfaces. Seedling survival and development are favored by moderate shade, protecting seedlings from climatic extremes. Under a closed forest canopy, upland ribes (*R. lacustre* and *R. viscosissimum*) do not thrive. Few survive, and those that do are ill-developed and present only a small target for infection. Stream-type ribes (*R. petiolare* and *R. inerme*) are more tolerant of shade, but do not occur extensively in forest stands.

Control of blister rust is favored by forest-regeneration methods that bring about full stocking of tree reproduction in the shortest possible time. Clear cutting followed by controlled broadcast burning and cutting by the seed-tree method are especially good in this respect. True, the stand is drastically opened up; but this is done all at once and a new stand starts immediately. Whatever ribes seed have been stored in the duff are either destroyed by fire or else encouraged to germinate promptly and all at about the same time. In open cuttings or on burns, ribes eradication is not difficult, and one or, certainly, two workings suffice to reduce the ribes population below the danger point. Eradication should be undertaken when the ribes seedlings are between 3 and 5 years old. Seedlings less than 3 years old are too hard to find, and many of them die naturally. Beyond 5 years of age, seedlings present a large target for infection and also begin to produce seed. Ribes-control activity is directed toward exhausting the present seed supply, suppressing existing ribes, and preventing further seeding in. Once the tree reproduction cover is complete, environmental conditions are increasingly inimical to ribes establishment and growth.

Light selective or light shelterwood cuttings also inhibit ribes. A full canopy is maintained and forest disturbance is held to a minimum. Ribes seedlings, if they appear, subsist poorly. After such cuttings it is very desirable, in the interest of ribes control, to leave slash unburned, since slash burning that falls short of broadcast is peculiarly stimulating to ribes germination. It is common to see in the scorched duff around the site of a slash pile a veritable ring of new ribes seedlings.

Stand-improvement operations in sapling and pole stands apparently do not add materially to the problems of ribes control. Weedings and cleanings in very young stands create little ground disturbance and consequently do not affect ribes much one way or another. Slash burning is not necessary. When thinnings and improvement cuttings are made in pole stands, the stands need not be opened materially and in any event will soon close again. Slash burning should be avoided as much as possible. Crown thinnings are preferable, as they require a minimum of cutting.

The possibilities of silvicultural aids to blister-rust control have not yet been fully explored. So far as is known, the main consideration is to maintain a full forest canopy as long as possible and when it must be removed replace it with a full cover of reproduction in the shortest possible time.

OTHER FOREST TREE DISEASES

Among other diseases that cause heavy losses and affect significantly the management of western white pine stands, the most prevalent and the best known are those causing heartwood rot. Some cause large losses in standing timber but seldom directly kill the trees. Others kill the trees but do not cause much rot in live timber. Those causing significant damage in western white pine stands are listed here with the causal organism, by tree species attacked, approximately in order of importance, the ranking closely following that given by Weir and Hubert (*66*).

Tree species and disease	*Causal organism*
Western white pine:	
Red ring rot	Ring scale fungus (*Fomes pini* (Brot. ex Fr.) Lloyd)
Red-brown butt rot	Velvet top fungus (*Polyporus schweinitzii* Fr.)
Spongy sap rot	Pine root fungus (*Fomes annosus* (Fr.) Cooke)
Shoestring rot	Honey mushroom (*Armillaria mellea* (Vahl. ex Fr.) Fr.)
Western larch:	
Red ring rot	
Brown trunk rot	Quinine fungus (*Fomes officinalis* (Vill. ex Fr.) Faull.)
Red-brown butt rot	
Dwarf mistletoe	Larch form (*Arceuthobium campylopodum* Engelm. *forma laracis* (Piper) Gill.)
Douglas-fir:	
Red-brown butt rot	
Red ring rot	
Shoestring rot	
Brown cubical rot	Sulphur fungus (*Polyporus sulphureus* Bull. ex Fr.)
Grand fir and western hemlock:	
Brown stringy rot	Indian paint fungus (*Echinodontium tinctorium* (Ellis) Ellis & Everh.)
Spongy sap rot	
Western redcedar:	
Yellow ring rot	(*Poria weirii* Murr.)
Red ring rot	
Brown cubical rots	Unidentified

In western white pine, as in most other tree species, quantity of rot almost invariably increases with age. This is shown clearly by the following data on average cull, exclusive of breakage in felling in western white pine trees, as measured in board feet (Scribner Decimal C). These figures were obtained through a region-wide breakage and cull study [25] based on actual utilization:

Age class (years)	*Cull percent*
81–100	3
101–120	6
121–140	10
141–160	12
161–180	16
181–200	18
201–300	20
301+	24
Average (weighted)	15

[25] ANDERSON, I. V., BREAKAGE LOSSES AMD CULL PERCENT OF TIMBER IN THE INLAND EMPIRE. Northern Rocky Mountain Forest and Range Expt. Sta. Applied Forestry Note 63. 1934. [Mimeographed.] Practically all cull recorded in this study was due to rot.

The percents given in this tabulation are conservative, excluding loss in cull trees (trees with less than 25 percent of their volume merchantable), standing dead trees, or windfalls. It is well known that decay, by lessening the mechanical strength of trees, indirectly causes much breakage and windfall. Also, particularly in the smaller tree sizes, percentage loss in value due to rot is often relatively greater than cull deduction in volume as customarily determined in log scaling.

From this tabulation it is apparent that although wood-rotting fungi cause heavy losses in later decades, the percentage of defect is not large in trees less than 120 years of age. In a study by Weir and Hubert (*67*) covering seven typical logging areas on the Coeur d'Alene Forest and one on the Kaniksu forest, rot, mostly red ring rot, was found in practically all trees more than 200 years of age (table 11). The conks or fruiting bodies of the fungi frequently did not appear until trees were more than 120 years of age. Rot was found to be more prevalent on low flats near creek bottoms than on slopes. This has been checked repeatedly by observation, and it seems well established that in trees of a given age the quantity of rot is appreciably greater on flat, low, poorly drained land than on well-drained slopes and benches.

TABLE 11.—*Relation of butt and trunk heart rot in western white pine to age of tree*[1]

Location and age class (years)	Rot in cubic volume of entire stand	Trees examined	Trees in each class containing heart rot	
	Percent	*Number*	*Number*	*Percent*
Bottom sites:				
41–60	0.0	37	0	0
61–80	.2	62	4	6
81–100	.7	116	43	37
101–120	1.7	111	71	64
121–160	3.1	129	86	67
161–200	15.7	76	72	95
More than 200	18.3	39	38	97
Total or weighted average	7.8	570	314	55
Slope sites:				
41–60	0.0	50	0	0
61–80	.1	60	4	7
81–100	.4	98	24	24
101–120	.5	100	41	41
121–160	2.3	235	174	74
161–200	2.4	99	82	83
More than 200	14.7	70	69	99
Total or weighted average	6.1	712	394	55
All sites	6.9	1,282	708	55

[1] After Weir and Hubert (*67*).

According to the above findings the average age at which the stand is most liable to first infection and below which infection rarely occurs is between 50 and 60 years. Infection of young trees with heartwood-rotting fungi cannot, of course, take place prior to the formation of heartwood. The fungi grow slowly, and decay rarely becomes visible externally in trees less than 70 years of age. Injuries play a large part in the incidence of infection. Weir and Hubert found that branch stubs and fire scars are the principal injuries by means of which fungi gain entrance to heartwood. The small quantity of rot found in trees less than about 120 years of age is accounted for, at least in part, by

the infrequence of such injuries on these younger trees. Older trees become infected not so much on account of loss of vigor as because they have more dead branch stubs, fire scars, and other avenues of infection. Of the trees in which infection could be traced to injuries, branch stubs were responsible for approximately 76 percent.

From the standpoint of timber management, the most important conclusion to be drawn from the studies just discussed is that rot in standing western white pine timber can be largely avoided by cutting at an age of 120 years or less. An added reason for cutting at this age is that removal of trees before they reach conk-bearing age would progressively reduce the danger to future timber crops. As a matter of fact a rotation age of 100 to 120 years is now commonly accepted for western white pine.

Although not credited with a great amount of damage to standing western white pine timber, the honey mushroom fungus, which causes shoestring rot in both root and butt, is known to be widely distributed in young and old stands of the western white pine type and to attack almost all the species in the type. It attacks trees of any age and either kills them outright or so weakens them, both physiologically and mechanically, that they become more susceptible to insect attack or wind throw. Because the victims of this fungus are so often missing from the stand at the time of logging, the damage it does is likely to be overlooked. Further investigation of this fungus is greatly needed.

The frequent classification of western hemlock as an inferior species in the western white pine type is due largely to its susceptibility to organisms causing heart rot, particularly Indian paint fungus. This fungus often renders the tree entirely worthless, and over large areas has completely destroyed commercial value of this species. In an advanced stage the tree may be nothing more than a living shell, with the heartwood entirely rotted away. Unfortunately, infection often comes comparatively early in the life of the tree. In a study by Hubert,[26] infection was first detected in trees 41 to 80 years of age, and of this group 46 percent were infected. In the 121- to 160-year group, 94 percent were infected, and 100 percent of those more than 200 years of age. It is believed that these figures are fairly representative of extensive stands of the western white pine type. In a study of hemlock heart rot in the Priest River drainage basin of northern Idaho, Weir and Hubert (*64*) found that the average age of earliest infection was about 50 years. The exact age of fungus incidence is difficult to determine and apparently is highly variable.

Indian paint fungus is most prevalent in western hemlock on wet, undrained sites at low elevations and least prevalent on slopes and better-drained soils. The characteristics of site having greatest influence on its prevalence seem to be moisture condition of the soil, porosity of the soil, and drainage, rather than soil composition or quality. The relation of tree vigor, crown class, and size to the entrance and progress of wood-rotting fungi has never been thoroughly demonstrated (*64*), but in general the better the tree's general vigor the less the quantity of rot. As in western white pine, age exerts the most positive influence, quantity of rot invariably increasing with age. In the Priest River study just mentioned, 84 percent of the infections observed were attributed to branch stubs and only 16 per-

[26] HUBERT, ERNEST E., FIRST PROGRESS REPORT ON THE STUDY OF DECAY IN WESTERN HEMLOCK. U. S. Dept. Agr. Forest Serv., Region One. 1929. [Unpublished.]

cent to fire scars, frost cracks, broken tops, and other injuries. The number of such injuries per tree consistently increased with age.

Although the susceptibility of western hemlock to decay presents a difficult problem, it does not preclude successful management of the species in the type. On some areas hemlock reaches sawlog size with very little rot and could be grown to pulpwood size on a rotation of 80 to 100 years with little loss from decay.

Grand fir suffers nearly as heavily as hemlock from rot, caused principally by Indian paint fungus. The foregoing discussion of this fungus on hemlock applies equally well to grand fir.

Little study has been made of rot in western redcedar; most of the information available is based on empirical observation. In general, the species is comparatively free from decay except at an advanced age. Veterans are usually heavily defective, frequently consisting of only a shell of living wood with the center entirely rotted away. Yellow ring rot caused by *Poria weirii* is the principal rot of living redcedar that has been definitely associated with a known fungus (*25*). Incidence is variable, and the reasons for this are not well understood. On some areas redcedar, even a large sawlog size, is almost entirely free from rot; on other areas trees of not more than pole size are heavily defective. As with other species, age seems to be the principal controlling factor. Redcedar characteristically develops as an understory tree, often undergoing long periods of heavy suppression and making correspondingly slow growth. Trees may be less than 6 inches in diameter at breast height at ages of 150 years or more, and rot is commonly observed to be much more prevalent in such slow-growing trees. It is believed that on favorable sites, if free from excessive suppression, redcedar can be grown at least to pole size [27] with little loss from rot. More pathological information is needed for successful management of this species.

Western larch and Douglas-fir are comparatively free from rot. Up to about 120 years of age, their loss of sound-wood volume from rot seldom becomes serious. This does not mean, however, that disease has no important bearing on the management of these species. Observations on permanent sample plots indicate that honey mushroom fungus may be a large factor in mortality of Douglas-fir, particularly in young stands. Until more is known of the activity of this fungus, little can be said as to its true role in management. Dwarf mistletoe, prevalent on western larch, causes trunk burls and large witches' brooms. The burls reduce the merchantable value of the tree. The brooms often break off, by their own weight or by overload of snow, causing a reduction in increment and sometimes total loss. The brooms that cause no breakage account for some reduction in increment by consuming stored foods that would otherwise contribute to cambial and apical growth.

It is evident from the foregoing that some of the most difficult silvicultural problems in the western white pine type are caused by disease. Control of these diseases must in nearly all instances be effected through silvicultural measures. The principal means by which at least partial control is possible are, as follows:

1. Harvest the timber crop before it has passed its pathological rotation age. In the long run this is by far the most effective remedy.

[27] Commercial pole sizes range from 20 feet to more than 75 feet. An average size is 35 feet, with an 8-inch top. Poles for telephone, telegraph, and power transmission lines are the most valuable redcedar product.

2. Practice forest sanitation, i. e., remove infected trees, either by felling or burning or by closer utilization.

3. Create conditions favorable to fast and vigorous growth, through sound methods of cutting and stand improvement. Disease does not flourish in healthy, vigorous forest stands.

4. Carefully control slash fires, which cause butt injuries, and adopt logging methods causing the least possible damage to the residual stand.

Insects

At all stages, regeneration of white pine forests is likely to be influenced by the attacks of destructive insects. Insects affect the management of the associated tree species of the type by attacking seedlings and the cones, seeds, buds, and cambium of the older trees. The most immediate management need is protection of timber stands that have reached or are approaching maturity.

In this problem the attacks of bark beetles (*Dendroctonus* spp.) on western white pine are of primary concern. The importance of bark beetles in the management of white pine increases proportionately with the age of the trees. Young, thrifty trees are fairly immune, though factors such as exposure, disease, and fire injury often render them susceptible to attacks of secondary beetles. In older stands the mountain pine beetle (*D. monticolae* Hopk.) exacts an annual toll, sometimes trifling but sometimes such that the residual stand is not worth harvesting. Since 1929, insect control measures consisting mainly of felling infested western white pine trees and destroying the insect larvae in the bark have been undertaken by the Forest Service with the technical assistance of the Bureau of Entomology and Plant Quarantine. It has been demonstrated that timely and adequate application of control measures will keep infestation in check and reduce losses. The aim in control is to keep the infestation endemic and to prevent the development of an epidemic which once under way is largely uncontrollable.

Though much of the destruction of timber by insects is clearly apparent and can be evaluated, some of the losses they cause are less appreciated. In fire suppression, insect-killed trees are a large adverse factor, since snags materially increase difficulty, cost, and danger of fire fighting and have alone been responsible for widespread conflagrations. Snag felling, which in many localities has become standard forest practice as a fireproofing measure, is considerably increased in cost where bark beetle attacks are unchecked. A still less noted result of bark-beetle activity is its effect on forest composition. In a mature stand destruction of white pine trees by insects causes a permanent decrease in the proportion of white pine, and therefore in stand value, as the pines are replaced for the most part by more tolerant trees of less value. Bark beetles thus assist in gradually transforming the ecologically unstable white pine forest into the climax forest of redcedar, hemlock, and other tolerant species.

Other Sources of Injury

Snow is the outstanding cause of mortality in dense immature stands of the western white pine type, as shown in table 12. Of the total mortality observed, measured in tree basal area, snow accounted for from 22 percent in Douglas-fir to 85 percent in western hemlock.

Comparison of basal-area loss with loss in number of trees affords a key to the relative size and kind of trees killed. Of the young white pine one-fourth of the trees killed by snow accounted for nearly half the basal area, whereas, as might be expected, approximately the reverse was true of deaths by suppression. In the denser stands snow definitely took the greatest toll of the smaller trees. Although snow losses may be rather evenly distributed throughout the stand, they are more often concentrated in groups or strips, in which all trees are laid down by the snow. The openings thus caused tend to enlarge from year to year.

Snow damage is not always entirely detrimental. To some extent it serves as a crude but effective natural selective thinning. Damage is largely confined to stands less than 80 years of age, and in the stands affected it is the suppressed, leaning, crooked, and weakly rooted trees that are most subject to snow injury; most of the stronger, straighter, and better-situated trees survive. In thinned stands, on the other hand, snow breakage is entirely detrimental and may be seriously so, especially if thinning has been heavy.

TABLE 12.—*Mortality on sample plots in young second-growth western white pine stands, by species and causes* [1]

Cause of death	Western white pine (2,071)		Western larch (238)		Douglas-fir (727)		Grand fir (658)		Western hemlock (163)		Lodgepole pine (33)	
	Trees	Basal area	Trees	Basal area	Trees	Basal area	Trees	Basal area	Trees	Basal area	Trees	Basal area
	Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
Snow	25	49	50	75	28	22	39	48	80	85	42	24
Suppression	49	24	32	15	35	17	27	19	13	7	19	26
Injuries	5	8	8	5	11	10	8	8	2	5	6	4
Disease	7	5	0	0	6	18	3	2	0	0	9	18
Insects	1	3	1	(2)	4	10	6	9	1	1	21	26
Wind throw	1	1	2	1	1	3	(2)	1	1	(2)	3	2
Unknown	12	10	7	4	15	20	17	13	3	2	0	0
Total	100	100	100	100	100	100	100	100	100	100	100	100

[1] Basis, 10- and 15-year records for permanent sample plots on 22 cut-over areas. Numbers in parentheses in headings indicate basis in number of trees.
[2] Less than 1 percent.

Susceptibility to wind throw is of critical importance in the application of regenerative measures. The wide use of the seed-tree method in the type is possible only because western white pine and its principal associates are fairly wind-firm and can be left as scattered seed trees. Data on wind-throw and wind-breakage losses in the second decade following logging, from 22 logging areas on which seed-tree, shelterwood, and selective cuttings were made, indicate no consistent differences in loss attributable to method of cutting. As summarized in table 13, the average loss from wind throw for the 7 associated species was only about 5 percent. Losses in the first 10-year period following logging are, however, usually much higher than in the second and succeeding decades. Although no observations were made on Engelmann spruce, general experience rates it as being less resistant than any of its associates.

Occasional heavy winds exact very severe losses from wind throw locally, and rarely over extensive areas. A single severe storm in the spring of 1932 blew down more than 90 percent of the white pine

Comparison of basal-area loss with loss in number of trees affords a key to the relative size and kind of trees killed. Of the young white pine one-fourth of the trees killed by snow accounted for nearly half the basal area, whereas, as might be expected, approximately the reverse was true of deaths by suppression. In the denser stands snow definitely took the greatest toll of the smaller trees. Although snow losses may be rather evenly distributed throughout the stand, they are more often concentrated in groups or strips, in which all trees are laid down by the snow. The openings thus caused tend to enlarge from year to year.

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	Trees	Basal area	Trees	Basal area	Trees	Basal area	Trees	Basal area	Trees	Basal area	Trees	Basal area
	Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
Snow	25	49	50	75	28	22	39	48	80	85	42	24
Suppression	49	24	32	15	35	17	27	19	13	7	19	26
Injuries	5	8	8	5	11	10	8	8	2	5	6	4
Disease	7	5	0	0	6	18	3	2	0	0	9	18
Insects	1	3	1	(2)	4	10	6	9	1	1	21	26
Wind throw	1	1	2	1	1	3	(2)	1	1	(2)	3	2
Unknown	12	10	7	4	15	20	17	13	3	2	0	0
Total	100	100	100	100	100	100	100	100	100	100	100	100

[1] Basis, 10- and 15-year records for permanent sample plots on 22 cut-over areas. Numbers in parentheses in headings indicate basis in number of trees.
[2] Less than 1 percent.

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Occasional heavy winds exact very severe losses from wind throw locally, and rarely over extensive areas. A single severe storm in the spring of 1932 blew down more than 90 percent of the white pine

seed trees left after logging on a small area in the Burnt Cabin Creek drainage on the Coeur d'Alene National Forest. In December 1934, unusually high winds following a period of heavy precipitation caused extensive damage on and near the Kaniksu National Forest. Damage was heaviest on about 3,000 acres of the Moore Creek drainage. Here losses ranged from 10 to 100 percent of the total stand, averaging about 30 percent. Approximately 3½ million board feet of western white pine saw timber was salvaged from this area.

TABLE 13.—*Wind-throw losses in the second decade following cutting in the western white pine type* [1]

Species	Loss in trees from residual stand		Species	Loss in trees from residual stand	
	1–13 inches d. b. h.	14+ inches d. b. h.		1–13 inches d. b. h.	14+ inches d. b. h.
	Percent	*Percent*		*Percent*	*Percent*
Western white pine	4	3	Douglas-fir	11	11
Western larch	7	4	Western redcedar [2]	3	3
Grand fir	4	6	Lodgepole pine [2]	9	18
Western hemlock	3	8			

[1] Basis, records for permanent sample plots on 22 cut-over areas. Losses on seed-tree, shelterwood, and selective cuttings are combined.
[2] Data weak.

Trees in cut-over stands are distinctly more susceptible to wind damage than trees in uncut stands. Spruce, in particular, is notoriously incapable of remaining standing in cut-over stands subject to strong winds. The heavy storm on the Kaniksu forest just mentioned blew down trees constituting 19 percent of the total basal area on a sample plot thinned the previous year in a very dense 75-year-old stand, while in an adjoining similar stand that had been left uncut the loss was negligible. In this instance white pine proved to be less resistant than larch; 28 percent of the white pine was wind thrown and only 6 percent of the larch. In addition to wind intensity, the extent of loss depends upon a combination of factors such as density of original stand, species, moisture content of soil, and presence or absence of rot. Rot that mechanically weakens the tree is an important indirect cause of wind throw, particularly in such species as grand fir and western hemlock.

Porcupines occasionally cause significant loss in western white pine stands, in which they apparently prefer western white pine and grand fir. Their activity results in girdling and in spiked tops. Porcupine damage is not, however, so serious in this type as in some others.

SEED SUPPLY

Any advantage one tree species may have over another in natural regeneration is usually first manifest in seed supply. Abundance and frequency of seed production, viability of seed and its susceptibility to destructive factors, and efficiency of seed dissemination, all directly affect natural regeneration and are of particular importance in an association of several species such as the western white pine type.

Seed Production of Western White Pine

ABUNDANCE AND FREQUENCY OF SEED CROPS

In comparison with associated species, western white pine bears relatively few cones. A crop of 40 cones per tree is rated good; one of 100 cones per tree is infrequent. The greatest recorded number of cones observed on one western white pine tree was about 600, found in 1935 on a 54-inch, 400-year-old veteran on the Priest River Experimental Forest. In 1936 this same tree bore 140 cones, again an unusually large crop. Cones are borne near the tips of the branches, and nearly all are produced in the highest quarter of the crown.

The number of seeds produced per cone varies widely. Zon (*68*), in a seed-production study in 1911, found from 6 to 184 seeds per cone, with an average of about 90 seeds. Brewster,[28] in a somewhat similar study made in 1915, found from 80 to 220 seeds per cone, with an average of about 145 seeds. About 120 seeds per cone is a fair average. Seed-destroying insects are in part responsible for the small number of seeds found in some cones. Aside from insect losses, which vary widely, number of seeds per cone depends chiefly on size of cone; the larger the cone, the more seed. Zon found that trees about 90 years old tended to produce larger cones than older trees. His data were collected on 4 sample plots, three of 0.5 acre each on the Kaniksu National Forest and 1 of 0.9 acre on the Coeur d'Alene forest, all in well-stocked stands containing a high proportion of western white pine. One plot was in a 90-year stand, 2 in a 145-year stand, and 1 in an overmature stand more than 200 years of age. Zon found also that the seeds in large cones were larger than those in small cones and had a higher germination percent, and concluded that "the larger the cones the better is the quality of the seed."

At the rate of 40 cones per tree, 120 seeds per cone, and average rate of germination of 44 percent (as given later), a tree bearing a good crop would produce, on the average, a few more than 2,000 germinable seeds. Occasional trees may, of course, bear many more than this. In Zon's study the largest number of germinable seeds produced by a single tree was 6,000, borne by a 28-inch tree; in Brewster's study, 7,300, borne by a 21-inch tree.

Zon concluded that, in the moderately good seed year of 1911, fully stocked, mature white pine stands bore from 2½ to 5 pounds of germinable seed per acre, or, assuming an average of 30,000 seeds per pound, from 75,000 to 150,000 germinable seeds per acre. In the exceptionally good seed year 1915, Brewster's study indicated production of some 280,000 germinable seeds per acre in fully stocked stands. These figures, representing seed productivity in virgin western white pine stands, have no great practical significance in regard to natural regeneration, which results for the most part from seed produced by partial stands left by cutting or fire. Later studies have been concentrated in cut-over stands and have dealt chiefly with periodicity of seed production and factors affecting seed production of individual trees.

The frequency with which good, fair, or poor seed crops are produced over a period of years is at least as important in the establishment of natural regeneration as the quantity of seed produced in a

[28] Brewster, D. R., memorandum and curves on western white pine seed production study, Northern Rocky Mountain Forest and Range Expt. Sta. 1916.

single year. Cones are borne by western white pine at irregular intervals. Complete cone-crop failures are rare; some cones are produced almost every year, although the quantity produced varies markedly from year to year. On 8 selected sample plots in cut-over stands on the Kaniksu and Coeur d'Alene forests the character of the cone crops was observed annually for the decade 1927–36. Individual trees were classified on the following scale: More than 15 cones, good; 6 to 15 cones, fair; 1 to 5 cones, poor. The cone crop on the plot as a whole was rated according to percent of trees 14 inches or larger in diameter bearing good or fair crops, as follows: More than 50 percent, good; 25 to 50 percent, fair; less than 25 percent, poor. Cone crops so rated for these 10 years are presented in table 14. Reasons for the variations in the recurrence of good, fair, and poor cone crops on individual plots were not clear. On plot 139, for example, 5 good cone crops were produced in the 9 years of observation, whereas plot 136 bore only 1 good crop in the same years, and on plot 121 not 1 good cone crop was found in 8 years. Plots 19, 24, 134, 135, and 144 bore good crops at 2- to 4-year intervals.

TABLE 14.—*Character of cone crops borne annually by western white pine trees 14 inches or larger in d. b. h. on eight sample plots, 1927–36* [1]

Year	Plot 19	Plot 24	Plot 121	Plot 134	Plot 135	Plot 136	Plot 139	Plot 144	All plots
1927	X	X	X	G	P	P	G	X	F
1928	X	X	F	P	F	P	P	P	P
1929	G	G	X	G	X	X	X	X	G
1930	G	F	F	F	P	F	G	G	F
1931	F	P	P	P	F	P	P	P	P
1932	G	G	F	G	G	G	G	G	G
1933	G	G	F	F	P	P	G	F	F
1934	P	P	P	P	F	P	P	P	P
1935	P	P	P	F	G	P	G	P	P
1936	P	P	P	F	P	P	F	P	P

[1] G=good, F=fair, P=poor, X=no record.

Despite these wide variations among individual plots, certain years were good seed years for nearly all plots. In 1932 all but one of the eight plots bore good cone crops. The 1929 crop was good for the three plots in this group that were examined, and it is known from other sources that 1929 was a generally good seed year. In 1934, poor crops were produced on all but one plot. For all eight plots combined, the 10-year period covered by the observations contained two good, three fair, and five poor seed years. This suggests that over an extended period good crops would recur about every 5 years on the average. If 1926, an exceptionally good seed year were included, the average intervals between good cone crops would be between 3 and 4 years.

In addition to consistent differences between individual stands within a locality, seed productivity varies widely between localities. This is brought out by table 15, which shows white pine cone production for a number of sample plots within three localities. In certain years the character of the cone crop was fairly uniform among all three, in others there were wide differences. The 1931 and 1934 cone crops were poor for all. In 1932 two localities had good crops and the third had a fair crop within 5 percent of being rated good. In 1930 and in 1933, one locality produced a good, another a fair, and the third

a poor cone crop. The Coeur d'Alene area produced good cone crops more frequently than the Priest River Valley areas.

TABLE 15.—*Cone production of western white pine in three different localities* [1]

Year	East side Priest River valley [2]			West side Priest River valley [3]			Burnt Cabin Creek [4]		
	G	F	P	G	F	P	G	F	P
1927		×				×			
1928			×		×				
1929							×		
1930	×					×		×	
1931			×			×			×
1932	×				×		×		
1933		×				×	×		
1934			×			×			×
Total	2	2	3	0	2	5	3	1	2
Average interval between good crops (years)	7/2=3.5						6/3=2.0		

[1] G=good, F=fair, P=poor.
[2] Basis, 5 sample plots in Fox and Benton Creek drainages, Kaniksu National Forest.
[3] Basis, 4 sample plots on west branch of Priest River, Kaniksu National Forest.
[4] Basis, 4 sample plots, Coeur d'Alene National Forest.

Extensive cone-crop observations made over a number of years by rangers on the national forests supplement observations of individual trees on permanent sample plots. These extensive observations were made primarily to ascertain where seed could be collected for nursery purposes. They began in 1908, but were rather sporadic for the first 13 years. From 1921 records were kept consistently until 1933, when the work was practically discontinued. The cone crops were rated as good, fair, or poor. Although based on rough ocular estimates covering extensive areas rather than actual tree counts, fairly accurate information on the general character of seed years resulted. Table 16 gives the seed-crop rating by year from 1921 to 1932, inclusive, for five national forests of northern Idaho, which include the greater part of the western white pine region. The ranger ratings agree closely with the combined sample-plot ratings given in table 14, and exactly as to good years insofar as they include the same years. The only differences are in 1928 and 1931, when "fair" and "poor" are transposed in the two sets of records.

With the help of these ranger observations, a continuous record of white pine cone crops has been pieced together for areas on and near the Kaniksu and Coeur d'Alene forests from 1908 to 1936, by combining with them permanent sample-plot and various other reports. This 29-year record, summarized in table 17, gives a fairly dependable basis for regional estimates of frequency of white pine cone production. It substantiates the showing of table 15 that the Coeur d'Alene forest tends to produce good cone crops more frequently than does the Kaniksu forest. For the white pine region, as a whole, good cone crops may apparently be expected every third or fourth year, although the productivity of individual areas may depart widely from this average.

TABLE 16.—*Character of western white pine cone crops in 1921–32 on five national forests in northern Idaho as estimated by forest rangers* [1]

Year	Kaniksu			Pend Oreille [1]			Coeur d'Alene			St. Joe			Clearwater			All forests [2]		
	G	F	P	G	F	P	G	F	P	G	F	P	G	F	P	G	F	P
																No.	*No.*	*No.*
1921			×	×					×			×				1	0	*5*
1922			×			×			×			×		×		0	1	*4*
1923	×			×			×			×						*4*	0	0
1924			×			×			×			×			×	0	0	*5*
1925		×				×					×				×	0	2	*2*
1926	×						×			×			×			*4*	0	0
1927	×			×				×				×			×	2	*1*	2
1928		×			×			×				×		×		0	*4*	1
1929		×		×				×		×					×	*2*	2	1
1930		×		×				×			×				×	1	*3*	1
1931		×			×			×				×			×	0	*3*	2
1932	×				×		×			×				×		*3*	2	0
Total	4	5	3	5	3	3	3	5	3	4	2	6	1	3	6	17	18	21
Average interval between good crops (years)	12/4=3.0			11/5=2.2			11/3=3.7			12/4=3.0			10/1=10.0					

[1] G=good, F=fair, P=poor.
[2] Italic numbers indicate the average rating of all forests for that year.

TABLE 17.—*Character of western white pine cone crops on Kaniksu and Coeur d'Alene National Forests as indicated by observations on permanent sample plots, ranger estimates, and other records, 1908–36* [1]

Year	Kaniksu			Coeur d'Alene			Year	Kaniksu			Coeur d'Alene		
	G	F	P	G	F	P		G	F	P	G	F	P
1908			×	×			1926	×			×		
1909	×			×			1927		×			×	
1910			×			×	1928			×		×	
1911	×				×		1929	×			×		
1912			×		×		1930		×			×	
1913			×	×			1931			×			×
1914		×			×		1932	×			×		
1915		×		×			1933		×		×		
1916			×			×	1934			×			×
1917	×			×			1935			×			×
1918		×				×	1936			×			×
1919			×			×							
1920	×			×			Total	8	8	13	11	6	12
1921		×				×							
1922			×			×	Average interval between good crops (years)	29/8=3.6			29/11=2.6		
1923	×			×									
1924			×			×							
1925		×				×							

[1] G=good, F=fair, P=poor.

RELATION OF CONE PRODUCTION TO TREE CHARACTERISTICS

Studies have shown a definite relation of cone production to certain tree characters, specifically crown class, tree class, diameter, and age.

In an early study of virgin stands by Zon (*68*), almost 99 percent of the total crop was found to be produced by dominant and codominant trees and the remainder by intermediate trees, suppressed trees

producing no cones at all. In a similar study Brewster [29] found that a little more than 90 percent of the total crop was produced by dominant and codominant trees.

Later studies have been made almost exclusively in cut-over stands, where the conventional crown classification of trees is inapplicable and classification by vigor has been substituted. Trees with large, dense, thrifty, well-formed crowns, good rate of growth, and a general appearance of good health have been classed as of good vigor; those with moderately good crowns and general health, as of fair vigor; and the remainder, as of poor vigor. Table 18, based on 5 annual observations of 473 identical white pine trees on 15 sample plots, shows the frequency of good, fair, and poor cone crops and of crop failures for trees of specified vigor and diameter. The outstanding conclusion from the table is that trees of good vigor produce cones much more abundantly and frequently, especially at the smaller diameters, than do trees of poor or fair vigor. If actual cone counts had been substituted for the qualitative classification, the balance in favor of the good-vigor trees would have been even more favorable because rating all crops of more than 15 cones per tree as good gives insufficient weight to the crops of 40 or more cones, which are borne mostly by good-vigor trees of large diameter. Good-vigor trees on reaching diameters of about 14 inches become effective seed bearers, bearing either good or fair cone crops in about half the years. Fair-vigor trees consistently produce fewer and poorer cone crops than do good-vigor trees of the same diameter and are not effective seed producers at diameters of less than about 20 inches. Poor-vigor trees are obviously ineffective seed producers.

TABLE 18.—*Effect of tree vigor and diameter on quality of western white pine cone crop, measured in percent of total crops possible* [1]

Tree-vigor class and diameter class (inches)	Good cone crop	Fair cone crop	Poor cone crop	No crop	Tree-vigor class and diameter class (inches)	Good cone crop	Fair cone crop	Poor cone crop	No crop
Good vigor:	*Percent*	*Percent*	*Percent*	*Percent*	Fair vigor—Con.	*Percent*	*Percent*	*Percent*	*Percent*
6	0	0	0	100	12	4	9	21	66
8	0	0	8	92	14	4	11	28	57
10	0	12	20	68	16	6	19	32	43
12	3	22	20	55	18	10	16	31	43
14	19	30	25	26	20	13	18	28	41
16	21	22	25	32	22	17	23	23	37
18	25	20	23	32	Poor vigor:				
20	24	22	20	34	6	0	0	0	100
22	20	24	27	29	8	0	0	2	98
Fair vigor:					10	0	5	13	82
6	0	2	5	93	12	1	6	21	72
8	0	3	11	86	14	2	12	18	68
10	3	5	16	76					

[1] Basis, 5 annual observations on 473 identical trees on 15 permanent sample plots in cut-over stands. Data are insufficient for estimating crops on poor-vigor trees over 14 inches d. b. h.

It is impossible to determine from the data available whether trees in cut-over stands differ significantly in cone productivity from trees of similar diameter and age in virgin stands. However, since cone bearing is known to be closely associated with tree vigor, it is to be expected that if trees left after logging increase in vigor they will bear more cones.

[29] Unpublished report already cited, p. 44.

Additional studies made in 1935 and 1936 have yielded further evidence as to the relation of tree vigor, diameter, and age to cone production. Actual cone counts were made in those years on all permanent sample plots suitable for cone-production studies and on a number of additional areas. Although the cone crops were poor on most of the areas studied, the relative contributions made by trees of good, fair, and poor vigor have much significance. Cone counts were made on 3,719 white pine trees 7 inches and larger in d. b. h. For the good-vigor, fair-vigor, and poor-vigor trees observed, respectively, the trees bearing cones amounted to 40 percent, 26 percent, and 12 percent and the number of cones per tree averaged 10, 7, and 5. In all, the good-vigor trees bore nearly 7 times as many cones as the poor-vigor trees. While the ratio between the cone-bearing ability of good-vigor trees and that of poor-vigor trees probably varies with the general quality of the crop, it is clear that the balance is heavily in favor of the former.

Further information on the character of trees bearing cones was gathered in 1935 on a 19-acre tract near Orofino, Idaho, used as a basis for an intensive logging and milling study (*54*). The 1935 cone crop in this particular locality was good. Cone crop, tree diameter, and tree class of each white pine tree on the tract were recorded before logging. The tree classification applied was as follows:

Class 1. The largest, most vigorous trees in the stand; trees that have developed without undergoing heavy competition. Usually the tallest in the stand.

Class 2. Trees well up in the dominant crown level but not of outstanding size. May be crowded, but not severely, on one or two sides.

Class 3. Trees with their crowns in the general crown level but severely pressed on one or more sides. Crown usually misshapen, rather short, and often thin. Bole long, slender, and well cleaned of branches.

Class 4. Trees definitely below the general crown level. Crown usually thin and short, bole slender.

Class 5. Scrubby, very inferior trees in the lower crown levels. Crowns very thin and short.

After logging, the ages of all trees except those too rotten at the stump were determined by counting the annual rings. Table 19 shows the relation of cone production to diameter, tree class, and age. Few good crops were borne by trees less than 16 inches in diameter. In the upper diameter range, a large percentage of the trees bore cones and the crop of cones per cone-bearing tree was heavier.

Tree class was found to afford a very close measure of cone production. Good cone crops were borne by 70 percent of the class 1 trees and 40 percent of the class 2 trees. Together, these two classes accounted for 92 percent of all the good crops. Tree classes 4 and 5 bore practically no cones.

The relation of age to cone production was not well defined, although there seems to be some tendency for the older trees to bear more and better cone crops. A close relationship is scarcely to be expected in any given stand; as a result of competition within the stand, age has little relation to diameter or tree class.

A similar difficulty in relating cone production to age has been encountered in all white pine cone-crop studies. Most stands of the white pine type are relatively even-aged, and so within any given stand clear-cut differences in cone productivity due to age can scarcely be

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expected. Consistent differences in cone productivity observed between stands are undoubtedly due to a number of interacting factors, of which age is only one.

TABLE 19.—*Relation of quality of cone production of western white pine to tree diameter, class, and age in percent of number of trees* [1]

Classification	Good-crop trees	Fair-crop trees	Poor-crop trees	No-crop trees	Basis, trees
Diameter class (inches):	*Percent*	*Percent*	*Percent*	*Percent*	*Number*
8–11.9	0	0	1	99	77
12–15.9	6	12	9	73	204
16–19.9	25	27	13	35	192
20–23.9	51	22	12	15	158
24–27.9	57	18	9	16	114
28–31.9	59	18	9	14	44
Tree class:					
1	70	15	6	9	111
2	40	27	12	21	353
3	9	12	12	67	210
4	0	1	1	98	103
5	0	0	6	94	17
Age class (years):					
91–110	5	17	11	67	18
111–130	25	17	10	48	201
131–150	32	16	11	41	166
151–170	38	26	4	32	116
171–190	42	12	12	34	26

[1] From Orofino, Idaho, study plot, 1935.

D. S. Olson, in charge of Forest Service planting in the northern Rocky Mountain region, reported in 1932 (*52*) that germination tests of seeds collected from trees 10 to 17 years of age, in which 7 lots of 600 seeds each were used, indicated a viability of 39 percent. Germination of seed collected from 21- and 26-year-old trees averaged 55 percent. While seed-bearing trees as young as these are relatively rare, and seldom produce more than 2 or 3 cones per tree only partially filled with seed, their combined effect may be appreciable in regenerating severely understocked areas such as burns.

Seed production becomes fairly frequent and abundant at about 70 years and tends to increase with age until the trees are about 20 inches in diameter. Beyond this point, productivity of the larger trees appears to have little relation to age or diameter but to depend chiefly on individual tree vigor and character of crown. Zon (*68*) reported that trees about 100 years old produced longer cones than trees more than 200 years old and proved that the larger the cone, the greater quantity of germinable seed per cone. On the other hand, as earlier stated, the greatest number of cones recorded on one white pine tree were found on a 400-year-old veteran.

EFFECT OF FIRE ON SEED MATURATION

Western white pines killed by summer fires have been known to mature considerable quantities of germinable seed. This happened on a large scale on the Kaniksu National Forest in 1926, when severe fires occurring in late July did not prevent the maturation of a large part of the bumper seed crop of that year. Remarkably abundant germination occurred in the spring of 1927, and as the summer was favorable for seedling survival many of the 1926 burns on the Kaniksu were amply restocked or even overstocked in the single year.

Germination tests in 1929 on seed from a number of trees bearing good cone crops and fire-killed under controlled conditions, resulted in 30 percent germination of seed from trees killed in June, 37 percent from those killed in July, and 54 percent from uninjured check trees. The experiment was, however, insufficient in scope to be conclusive.

KIND AND NUMBER OF SEED TREES NEEDED

Specification of the kind of trees to leave for seed production is not difficult in the light of findings already reviewed. Good vigor, recognizable by thrifty, well-formed crowns, good rate of growth, and general appearance of health, is of first importance. The main conclusion of the cone-crop studies was that the bulk of the crop is borne by trees of good vigor. Trees of good vigor begin effective seed production at diameters of about 14 inches, and fair-vigor trees at diameters of about 20 inches; poor-vigor trees are ineffective seed producers at any diameter. In general, among trees similar as to vigor, the larger the tree the more seed it will produce. Trees less than about 70 years of age are seldom good seed producers, but above 90 or 100 years, the productivity of trees seems to depend more upon individual vigor and diameter than age. Where other factors are equal, however, there is a tendency for seed production to increase with age until the tree reaches full maturity.

Estimating the number of white pine seed trees necessary to produce a desired number of seedlings is exceedingly difficult. Seed and seedling losses, as well as seed production, must be considered. Furthermore, white pine being distinctly periodic in seed production, it cannot be expected that seed trees will be effective over any period so short as 2 or 3 years. With the help of certain assumptions, however, it may be possible to estimate the number of seed trees needed with sufficient accuracy to serve as a guide until additional knowledge is available. An example will serve to illustrate this.

Suppose that 1,200 established western white pine seedlings per acre are desired within a 5-year period following logging. On 75 percent of the cut-over area this would result on the average in adequate stocking. Because of depletion by weevils and rodents, germination losses, and high mortality of newly germinated seedlings, it is estimated that only about 2 percent of the seed produced will result in established seedlings. Accordingly, a total yield of 60,000 seeds per acre over the 5-year period will be required to make sure of 1,200 established seedlings. Assuming 120 seeds per cone, 500 cones must be produced. According to the averages presented in table 18, 18-inch good-vigor trees produce good crops 25 percent, fair crops 20 percent, and poor crops 23 percent of the time. If good cone crops average 40 cones per tree, fair crops 10 cones, and poor crops 3 cones, 18-inch good-vigor trees can be expected to produce on the average about 65 cones over a 5-year period, and 8 such trees per acre are sufficient to provide the 500 cones needed. On the same basis, 16 fair-vigor trees would be required. Similar calculations can be made for trees of larger or smaller diameter or for a longer seeding period. Obviously, these estimates are subject to considerable error, but that they are approximately correct is shown by the fact that on national-forest timber sales, where standard practice has been to leave 2 to 6 white pine seed trees per acre, mostly of good

vigor, satisfactory restocking to white pine has in most instances taken place in a 5- to 10-year period. Frequently, as has been pointed out, seed already in the forest floor at time of cutting, or falling during the year of cutting, will materially supplement seed produced by trees left for seeding purposes.

Seed Production of Associated Species

Seed production of species associated with western white pine is exceedingly important in its effect upon the composition of reproduction stands. Provision of sufficient white pine seed trees will by no means insure the desired proportions of white pine; the abundance and reproductive capacity of other species present must also be taken into account.

On 12 permanent sample plots in cut-over stands, the character of the cone crop of all white pine associates was observed annually throughout the 8-year period 1927–34. Character of cone crop was rated as follows:

Larch, Douglas-fir, grand fir, and Engelmann spruce:
- Poor: 1 to 20 cones per tree.
- Fair: 21 to 40 cones per tree.
- Good: More than 40 cones per tree.

Western redcedar and western hemlock:
- Poor: Scattered cones only.
- Fair: Intermediate condition.
- Good: Branches sag from weight of cones.

The crops borne by the trees 13.6 inches d. b. h. or larger are summarized in table 20, and compared with those produced by white pine. Hemlock and redcedar were outstandingly prolific seed bearers, producing five and four good crops, respectively, in 8 years. During the same period western larch trees produced three good, two fair, and three poor crops. Although Douglas-fir is shown as producing only one good crop in 8 years, the Douglas-fir cone crops of 1932 and 1933 each came within 2 percent of being rated good. Thus, from available data, Douglas-fir approximately equals larch in productivity. Grand fir seems to be the least abundant seed producer of the major white pine associates.

Table 20.—*Character of cone crops produced by trees 13.6 inches d. b. h. or larger of the principal species of the western white pine type in 1927–34, inclusive* [1]

Year	Western white pine			Western larch			Douglas-fir			Grand fir			Western redcedar			Western hemlock		
	G	F	P	G	F	P	G	F	P	G	F	P	G	F	P	G	F	P
1927		×				×		×				×			×			×
1928			×			×		×				×		×			×	
1929	×					×			×		×			×		×		
1930		×		×			×					×		×		×		
1931			×	×					×			×	×			×		
1932	×			×				×				×	×			×		
1933		×			×			×				×	×				×	
1934			×		×			×			×		×			×		
Total	2	3	3	3	2	3	1	5	2	0	2	6	4	3	1	5	2	1

[1] G=good, F=fair, P=poor. Ratings based on annual observations on 12 sample plots in cut-over stands.

By combining the observations of cone production on permanent sample plots with forest rangers' estimates covering more extensive areas, it has been possible to build up a 14-year record of cone crops, according to which the average interval between good cone crops is 2.1 years for hemlock, 2.8 years for redcedar, and 4.7 years for larch and Douglas-fir. The record for grand fir is unreliable.

There is little evidence that conditions in any one year ever conduce to uniformly good cone crops for all species. In the period 1927–34, the nearest approach to a good seed year for all species was 1932, when four bore good crops and one fair. The poorest seed year was 1927, in which two of the species had fair and four had poor crops. In other years little consistency between species is evident, probably the result of varying susceptibility of the several species to frost, wind, rain, and other climatic elements during flower pollination and setting of the fruit.

TABLE 21.—*Number of seeds per acre caught annually in seed traps on two permanent sample plots on cut-over areas*

[Quantities in thousands; i. e., 000 omitted]

Plot and species	1927	1928	1929	1930	1931	1932	1933	Average
Plot 134:								
Western white pine	0	1.0	19.0	6.0	0.5	9.6	1.1	5.3
Western larch	0	0	0	8.0	.5	.5	1.7	1.5
Douglas-fir	3.0	2.0	8.0	9.0	0	7.0	5.1	4.9
Grand fir	0	0	6.0	71.0	0	26.5	16.0	17.1
Western redcedar	3.0	29.0	44.0	5.0	146.0	475.5	74.8	111.0
Western hemlock	2.0	525.0	161.0	260.0	229.5	527.5	305.1	287.2
Miscellaneous species	0	3.0	0	0	.5	0	5.1	1.2
Plot 23:								
Western white pine	--------	--------	3.0	7.0	1.0	3.5	8.7	4.6
Western larch	--------	--------	77.5	166.0	121.5	10.5	8.0	76.7
Douglas-fir	--------	--------	10.0	16.0	1.0	2.5	11.5	8.2
Grand fir	--------	--------	63.0	27.5	25.0	.5	1.3	23.5
Western redcedar	--------	--------	21.0	2.5	0	0	0	4.7
Western hemlock	--------	--------	1,578.0	448.0	2,536.5	538.5	25.3	1,025.3

As with white pine, cone production of the principal white pine associates increases with tree diameter and vigor. Excepting redcedar and hemlock, which bear seed at distinctly smaller diameters than other species, the principal associates behave very much like white pine. The available information is insufficient for detailed comparisons.

An indication of the actual numbers of seeds produced by the associates is given by table 21, showing for two sample plots on cut-over areas the numbers of seed caught in seed traps (pl. 5) over a period of years. Outstanding among the seed-producing characteristics of the principal white pine associates are the great abundance and frequency of seed crops of redcedar and hemlock, the most tolerant species. The capacity of these species, especially hemlock, for producing tremendous numbers of seeds largely explains their abundance in certain portions of the region. In some years the seed catch of the small-seeded hemlock and redcedar was a million or more per acre. The superior hardiness and vigor of white pine, larch, Douglas-fir, and grand fir seedlings in some measure make up for less abundant seed production, in that these species are able to become established under habitat conditions too severe for "cedar" and hemlock.

Seed Dissemination

SEASON

Although most species in the western white pine type begin to disseminate their seed in late August or early September, seasonal distribution of seed fall differs considerably among the species. Seed-trap observations made annually for 8 years in a 300-year-old stand and a vigorous 75-year stand, both near the Priest River Experimental Forest, have yielded some information as to when the seed of the principal species in the type reach the ground (table 22). Western white pine disseminated most of its seed crop in the early fall. About 15 percent of the current crop reached the ground before September 1, about 85 percent by the end of October, and only 15 percent during the late fall and winter. Grand fir released its seed almost as early and completely, about 80 percent falling before the end of October. Western larch and Douglas-fir usually disseminated their seed a little later than did white pine and grand fir, especially in the older stand, only 65 to 80 percent of the crop falling by the end of October. Seed of western hemlock and western redcedar fell considerably later than those of the other species; the fall was heaviest in October, but 35 to 45 percent occurred after November 1.

Table 22.—*Distribution of seed fall of principal species in the western white pine type by periods* [1]

Species	Midsummer to Aug. 31	September	October	Nov. 1 to midsummer	Average seed fall per acre per year
300-YEAR-OLD STAND (PLOT 151)					
	Percent	*Percent*	*Percent*	*Percent*	*Number*
Western white pine	14	59	10	17	39,500
Western larch	5	30	31	34	45,900
Douglas-fir	6	22	37	35	3,000
Grand fir	1	64	13	22	12,800
Western hemlock	5	4	43	48	956,500
Western redcedar	14	16	24	46	3,003,000
75-YEAR-OLD STAND (PLOT 101)					
Western white pine	17	52	16	15	3,500
Western larch	24	35	19	22	17,500
Douglas-fir	4	74	7	15	8,800
Grand fir	8	64	14	14	1,800
Western hemlock	5	14	49	32	3,000
Western redcedar	19	19	23	39	5,000

[1] Basis, periodic observations in each year of 1928-35, inclusive, on catch in 16 quarter-milacre seed traps.

Records for these two plots indicate considerable variation from year to year in period and seasonal distribution of seed fall, both for all species and for individual species. In 1933 dissemination of seed of all species began late and an unusually large proportion of the crop reached the ground after November 1. A possible explanation is that the unusually rainy fall weather of that year retarded the ripening and opening of the cones and consequently the dissemination of seed. Other differences observed between the plots may be partially due to the wide disparity in age. The veteran stand produced many times more seed than the 75-year stand—redcedar and hemlock in

particular. In the old stand these species formed a large proportion of the dominants; in the young stand, they were strongly suppressed. It is possible that both degree of suppression and age of the seed trees affect the time of seed dissemination to some extent. Other factors such as site, aspect, and various climatic elements undoubtedly have some influence, but their actual effect is not known.

DISTANCE

The distance to which seed are disseminated from the parent tree depends upon the combined effect of a number of factors such as height of tree, topography, air movements, character of the seed (i. e., size, weight, wings, and general ability to "fly"), action of birds and rodents, and season of dissemination. In the study of white pine reproduction originating from a known seed source, already cited on page 9, about 70 percent of the seedlings were found within 200 feet of the seed source and about 90 percent within 400 feet. In some observed instances white pine seed has apparently been disseminated for distances of half a mile or more, but not in quantities sufficient to be relied upon for adequate natural regeneration. Isaac [30] has measured the flight of forest-tree seed by releasing them over snow from a kite at known elevations and wind velocities and observing the distance they traveled before reaching the ground. Of the species he tested that are common in the western white pine type, seed of western hemlock was found to travel the farthest. White pine was next, closely followed by Douglas-fir, and seed of western redcedar made the shortest flight. The main point established by the available data is that seed sufficient to produce adequate reproduction is distributed not farther than about 400 feet from the parent tree.

Seed Storage

Seed of all species in the western white pine type is stored naturally in the duff when it falls from the parent tree, and retains viability until the following spring. Investigations have shown, however, that western white pine is the only species in the type whose seed remain viable in appreciable quantity for more than the normal overwinter period. An experiment in which seed of all the principal species in the type were stored in the duff under a rather dense virgin stand and samples annually tested in sand flats for viability showed about 40 percent of the white pine seed to be viable after one winter's storage and about 25 percent after two winters' storage. Slightly less than 1 percent retained viability after 3 or 4 years' storage, and only an occasional viable seed was found after 6 years' storage. Seed of no other species tested retained viability for more than the normal overwinter period.

Another check on the viability of white pine seed after natural storage in the duff is available from 200 small quadrats, located on several cut-over areas, that were screened after the heavy seed crop of 1926 fell to the ground. The screening excluded all seed from later crops. Annual examinations for 8 years showed that practically all the seed present in the duff in 1926 germinated within 2 years.

[30] Isaac, Leo A., Measured flight of seed of Douglas fir and its associates. Pacific Northwest Forest and Range Expt. Sta. 1928. [Unpublished.]

Larsen (*38*), after an elaborate study of seed stimulation, concluded that the tendency of western white pine seed to remain viable beyond one season is due to the impermeability of the seed coat, not to any inherent physiological character of the seed embryo or endosperm such as need of a resting period after ripening. The tendency to delayed germination is largely overcome by fall sowing, the normal occurrence in this type.

Seed Losses

Only a very small proportion of the seed produced in the cones germinates—probably, on the average, about 1 or 2 percent. Losses begin on the tree. Squirrels (*Tamiasciurus hudsonicus richardsoni*) often harvest the major share of the crop. In specific instances they have been observed to take from 90 percent to practically all of the white pine crop. White pine cones are preferred to those of other species, but where the white pine crop is light, cones of other species are harvested. Undoubtedly a larger proportion of the seed crop is taken in poor seed years than in good ones. Various species of insects reduce seed crops of all the species by feeding on buds, flowers, immature cones and seed, and mature seed. Instances have been noted in which they destroyed practically the entire white pine cone crop in certain localities. In 1930, for instance, all white pine cones produced on two sample plots on the Kaniksu forest were attacked by insects of undetermined species and the seed destroyed. On other sample plots on the Kaniksu and Coeur d'Alene forests no damage was noted. Difficulty in collecting sufficient seed for planting purposes has been experienced on account of extensive insect damage.

Additional seed is destroyed after reaching the ground, through the action of fungi, insects, and rodents. Rathbun-Gravatt (*15*) has shown beyond doubt that many seeds are killed prior to germination by damping-off organisms, and many investigators have noted pregermination losses from other causes. Rodent depredations, for example, are the principal obstacle to successful direct seeding.

The total effect of the various agencies causing seed losses on natural regeneration is indubitably great, and it is unfortunate that so little is known about them. Better information on seed losses is necessary for accurate evaluation of the efficacy of seed trees.

Source of Seed for Natural Regeneration

"What was the source of seed?" has been one of the most frequently asked and discussed questions in western white pine silviculture. Quest for the answer, necessary to an understanding of natural regeneration, has constituted a large part of silvical research in the type. Cutting methods have been devised and revised as new discoveries were made. Investigations of seed supply and storage and of factors controlling initial establishment of natural reproduction have now made it possible to piece together a fairly definite answer to this question. Seed may be divided according to origin into three classes: (1) Stored seed, i. e., seed stored in the duff longer than the normal overwinter period; (2) coincident seed, produced at the time of cutting or burning or within the preceding year; and (3) subsequent seed, produced by the residual stand.

Though the idea, evolved largely by Hofmann (*23*), as to the importance of stored seed was exaggerative for many years and exerted an undue influence on marking rules, the theory outlined was in part correct. Later and more comprehensive studies showed that seed deposited in the forest floor before or immediately after cutting or fire plays a part, sometimes a very important one, in regeneration of western white pine stands. Even seed stored in the duff for longer than the normal overwinter period is a factor in regeneration, even though of much less importance than was once believed. The definite limitation on the seed-in-the-duff theory is the fact that western white pine seed so placed will rarely retain its viability for more than 2 years, and that seed of none of the other species will do so for more than the usual overwinter period.

Natural regeneration of quite adequate density often results from stored seed and coincident seed combined, and it is very difficult in such cases to segregate the two seed classes. Undoubtedly some at least is from stored seed, since on many areas reproduction is definitely concentrated where the duff remains undisturbed and is lacking where the duff has been burned. As was previously mentioned, extensive areas on the Kaniksu National Forest that were burned over in 1926 reproduced abundantly in 1927 as a result of a good seed crop in 1926, which was only partially destroyed by the fire, and favorable conditions for seed germination and seedling survival in 1927.

The importance of a continuing seed source subsequent to cutting has been established by studies of the time of origin of reproduction on numerous cut-over and burned-over areas. Table 23 shows the number of western white pine seedlings annually becoming established (that is, surviving their second season) during a 10-year period following cutting on 10 representative western white pine areas.

TABLE 23.—*Number of seedlings established in decade following logging on 10 representative western white pine areas, by year of origin*

Year of origin, following cutting [1]	Phil McManimin	Rose Lake, Donkey	Rose Lake, Cathcart	McGoldrick, Sands Creek	Rose Lake, Leiberg	Ryrie and Wright	Dalkena, Section 2	Corcoran, Casey, and Foster	National Pole Co.	Humbird, Section 19	Average, white pine	Average, all species
1	31	29	5	65	7	150	15	60	127	26	52	261
2	127	148	34	188	26	236	66	51	83	65	102	656
3	527	327	54	208	28	75	316	30	41	44	165	988
4	577	386	84	238	40	321	1,054	102	79	270	315	1,265
5	513	208	217	209	52	307	1,329	102	51	141	313	1,496
6	304	0	250	227	60	332	1,195	123	88	141	272	1,634
7	247	59	185	187	123	282	887	84	136	87	228	1,953
8	185	107	191	166	54	467	587	106	165	108	214	1,857
Total	2,511	1,264	1,020	1,488	390	2,170	5,449	658	770	882	1,660	10,110

[1] Only seedlings surviving the second season after cutting are considered established. Hence seedlings originating during the last 2 years of the decade are not recorded.

Table 23 shows very clearly that the reproduction stand was built up fairly evenly over the period. The combined contribution made by stored and coincident seed can be rather accurately determined, as seed-storage studies have shown that practically all seedlings from these sources are restricted to the first 2 years for western white pine

and to the first year for the other species. Assuming 500 established white pine seedlings per acre as the minimum number for satisfactory regeneration to that species, and including seedlings originating during the first 3 years (a generous allowance), only 2 of the 10 areas could possibly be classed as satisfactorily reproduced to white pine mainly from stored and coincident seed. Similar studies of a large number of cut-over western white pine areas have shown that reproduction from stored and coincident seed is satisfactory on not more than 1 out of 4. The necessity of scattered seed trees or some other continuing seed source is apparent.

Observations on burned-over areas have confirmed the finding that reproduction stands frequently originate over an extended period of years from subsequent seed. Apparent contradictions in the form of excellent reproduction stands on old burns, with scarcely a living tree of the parent stand in sight, can often be explained by seeding coincident with the fire or by the observed fact that in a stand fatally damaged by fire a considerable number of trees may survive for several years and bear considerable quantities of seed. A good example of this is furnished by two sample plots established on the Kaniksu forest in 1927 on areas burned over in 1926. As is shown in table 24, a considerable number of white pine trees survived the fire. Most of them died within 2 years, but a few were still alive 10 years after the fire. Annual seedling counts on these plots showed that although the largest numbers of seedlings originated in 1927 and 1928, appreciable numbers appeared practically every year for 8 more years.

TABLE 24.—*Survival of western white pine trees 10.6 inches d. b. h. and larger, on two burned-over sample plots on the Kaniksu National Forest, by years*

Year	Plot 129 [1]	Plot 133 [1]	Year	Plot 129 [1]	Plot 133 [1]
	Number	*Number*		*Number*	*Number*
1926	31.6	54.6	1932	3.3	3.4
1927	18.7	16.0	1933	3.0	3.2
1928	10.0	8.5	1934	2.0	3.1
1929	5.7	4.7	1935	2.0	3.1
1930	5.3	4.3	1936	2.0	3.1
1931	3.9	3.7			

[1] Number of trees alive before the fire, which occurred in July 1926.

The principal reason why stored and coincident seed cannot be relied upon for adequate regeneration is not inadequacy of original supply so much as heavy losses of seed and seedlings. Insects, squirrels, and the like may destroy the major part of any annual seed crop. Furthermore, unfavorable conditions for germination and early survival may prevent a large number of seedlings from becoming established, despite a plentiful supply of seed on the ground. Often the supply of seed in the duff under a mature stand is materially reduced by germination before the stand is cut—germination that usually constitutes a complete loss, the seedlings diappearing rapidly. Conversely, if seed losses are small and growth conditions favorable, a good crop of seedlings may originate from a relatively small seed crop. On account of the heavy seed and seedling losses that may occur in any given year or even in two or three successive years, a continuing seed source is usually necessary to obtain adequate natural regeneration in the western white pine type.

GERMINATION

Seed of all species common in the western white pine type normally germinate in the spring in soil wet to field capacity by melting snow. Phenological observations at the Priest River Experimental Forest, Idaho, and at Savenac Nursery, Mont., and seedling studies (*19*) indicate that germination begins on exposed sites at the lower altitudinal limits of the type between April 20 and May 10. Germination is always later by a week or more at Savenac Nursery, at 3,150 feet elevation, than on the Priest River Experimental Forest, at 2,300 feet elevation, and by a month or more at higher elevations and on protected sites such as north slopes, where snow may remain until April 30 or later.

Germination is later also on areas sheltered by a forest canopy or by topography. The effect of a forest canopy is well illustrated by table 25, which summarizes the course of seedling germination in 1932 and 1933 in prepared seed beds at stations in full sun, part shade, and full shade on the Priest River Experimental Forest. These stations are only a few hundred feet apart and differ only as to shade. Both time and rapidity of germination varied markedly with character of overhead shade. Germination began and ended about 3 weeks earlier at the full-sun station than at the full-shade station in a dense mature stand. Although most seedlings were up by June 5 at the full-sun station, and by July 15 in full shade, straggling germination continued until the surface soil dried out, about July 1 in full sun and a month later in full shade. As Jemison (*28*) has shown, temperature of air and soil, evaporation rate, and humidity are all significantly lower at the sheltered stations.

TABLE 25.—*Course of germination of fall-sown seed of the six principal species in prepared seed beds with different degrees of shade* [1]

Course of germination and year	Full sun	Part shade	Full shade
Snow gone: 1932	Apr. 10	Apr. 15	May 5
Germination begins:			
1932	Apr. 28	May 1	May 20
1933	May 1	May 10[2]	[2]May 24
Germination practically completed:			
1932	June 5	June 30	July 15
1933	May 30	do	Do.
Germination ends:			
1932	July 5	July 27	July 28
1933	June 23	July 10	Aug. 1

[1] Priest River Experimental Forest.
[2] A very few seedlings were up May 1.

Table 26 gives the course of germination on three study areas on the Kaniksu National Forest, all located in typical seed-tree cuttings in the western white pine type. These records were obtained by frequent examination of permanent sample-plot quadrats. Period of germination compares closely with that shown by the data for the prepared seed beds on the Priest River forest. Germination was practically completed about July 1 on the exposed flat, about July 15 on the dry ridge and southerly slope, and about August 15 on the sheltered north slope.

It has been found that in spite of material variation in the spring weather—for example, marked differences in the duration of snow cover—seedling germination on similar sites usually begins about the same time each year. No material differences with respect to either time or rapidity of germination have been observed among the species of the type under natural conditions, perhaps because the available data are too meager.

Under natural conditions germination is probably stopped by drying out of the topsoil or duff. Drying early in the season results in either a smaller total germination in species slow to start or carrying over of some viable western white pine seed into the second season.

TABLE 26.—*Progress of germination (percent of total) of the six principal species on three typical cut-over areas*[1]

Approximate examination date	Sheltered north slope		Ridge and southerly slope, 1931	Exposed flat, 1931
	1930	1931		
	Percent	*Percent*	*Percent*	*Percent*
June 15	50	35	50	80
July 1	70	63	71	96
July 15	83	84	100	100
Aug. 1	92	97		
Aug. 15	96	100		
Sept. 1	100			

[1] Kaniksu National Forest. Elevation: North slope 2,800 feet; ridge, south slope, and flat, 3,000 feet.

Moisture, warmth, and oxygen are the principal factors essential to germination of tree seed. As soil moisture is usually plentiful in the spring and sufficient oxygen is rarely lacking in well-drained upland soils, it seems probable that soil temperature controls the beginning of germination in the western white pine type. Although the exact requirements of the associated species are not known, Larsen (*35*) has shown temperature to have a very important effect upon rate of germination and to be perhaps the principal agent governing this process under natural conditions. Table 27, based on Larsen's data, indicates the effect of soil temperature upon the rates of germination, under favorable moisture conditions, of four species common in white pine stands.

Light, though essential to the germination of some seed (*8*), is probably of little importance with seed of western white pine and associated species. Although light may have some stimulating effect, it has been demonstrated beyond doubt that seed of all tree species common in the western white pine region will germinate satisfactorily even in the shade of dense mature or overmature timber stands if other conditions are favorable. Germination of appreciable percentages of western white pine seed stored in duff in the shade of dense young to overmature stands has been reported, for example, by Brewster [31] and by Haig (*17*, *19*).

[31] See footnote 16, page 10.

TABLE 27.—*Germination per day of four principal species in relation to daily mean soil temperature* [1]

Species	51°–60° F.	61°–70° F.	71°–80° F.
	Percent	*Percent*	*Percent*
Western white pine	0.0	0.0	1.25
Douglas-fir	.4	1.5	2.5
Western redcedar	(2)	.1	4.0
Western hemlock	(2)	(2)	4.3

[1] Averages for period of most rapid germination. After Larsen (*36*).
[2] No test.

Germination is materially affected by the character of the surface layer in which it occurs. Duff, for example, is a very poor germinating medium under certain circumstances, particularly on exposed sites (*4, 19, 37*). At the full-sun station on the Priest River forest, germination was never satisfactory on duff, even though seed was sown on this surface much more heavily than on others. In two separate sowing experiments on a clear-cut exposed flat, Larsen (*37*) found germination 2 to 12 times as good on burnt and natural mineral surfaces as on duff. According to records obtained under the generally more favorable conditions left on typical seed-tree cuttings (table 28), germination on duff did not differ greatly from that on other surfaces for the hardier and larger-seeded species, western white pine, grand fir, and Douglas-fir. Germination of the smaller-seeded species, however, was distinctly poorer; hemlock and redcedar germinated 5 to 10 times as abundantly on burnt and unburnt mineral surfaces as on duff. The reason for this difference is not clear but it seems to be related to size of seed. Probably the rather rapid fluctuation of moisture content usual in the duff is partly responsible, and the fact that small seed dry out more rapidly than large seed. Under greenhouse conditions, where a favorable degree of moisture was maintained by repeated watering, Fisher (*11*) found no significant differences in germination between ash, duff, mineral, and rotten-wood surfaces, though there was a tendency for germination to be less on duff than on ashes and on rotten wood.

TABLE 28.—*Germination on burned-over and natural mineral soil and on rotten wood in terms of germination on duff,*[1] *on typical seed-tree cuttings*

Species and seed per pound (number)	Germination on—		
	Burned-over mineral soil	Natural mineral soil	Rotten wood
	Percent	*Percent*	*Percent*
Western white pine (26,700)	88	178	90
Grand fir (34,100)	46	148	77
Douglas-fir (45,100)	107	94	107
Western larch (125,200)	199	320	99
Western hemlock (299,400)	569	707	350
Western redcedar (353,300)	1,079	960	141
Average	348	401	144

[1] 100 percent=germination on duff.

Although more investigative work is necessary to determine accurately the role of soil cover in seed germination on partly shaded areas, it can be stated with confidence that establishment of the smaller-seeded species, particularly redcedar and hemlock, is aided by such measures as tend to expose the mineral soil on considerable portions of cut-over areas.

The best data available on the viability of fresh seed of western white pine and its principal associates as determined by sandflat germination tests in the greenhouse, at the Priest River Experimental Forest and at Savenac Nursery (*33*, *35*, *51*) are averaged in the following figures:

	Percent
Western white pine	44
Douglas-fir	41
Western larch	30
Western redcedar	73
Western hemlock	65
Grand fir	12

Germination percent is usually higher in the greenhouse, where moisture and temperature conditions can be kept favorable, than under natural conditions. In nursery work this is recognized, and a correction factor based on experience is used to adjust for differences between germination in sand flats and germination in seed beds. However, the relatively short period used in testing seed under greenhouse conditions tends to result in underestimate of the number of seed that are capable of germinating. Even 200-day greenhouse tests are too short to permit complete germination of western white pine seed, which under natural conditions may remain viable in the duff for 2 years. Under favorable conditions, germination of western white pine and its associates in the field may approach the values shown in the tabulation.

A good measure of the comparative reproductive ability of white pine and its associates is the number of seedlings of each species produced by a stand of given composition over a definite period of years. Such a measure is afforded (table 29) by comparison of the percent of each species in the total residual stand and the percent in total germination over a period of 6 to 8 years on 12 permanent sample plots on cut-over areas. The high reproductive ability of redcedar and hemlock is very apparent. For each of these species the percent of total germination is distinctly higher than that of total residual stand. The 2 species together, constituting only a little more than half of the residual stand, accounted for 93 percent of the total germination; whereas the 4 other species together provided only 7 percent.

In interpreting table 29 it must be remembered that these figures represent total germination, not established seedlings. Redcedar and hemlock, for example, produce prodigious numbers of seed, but a very small proportion of their seed develop into established seedlings. The superior hardiness and vigor of white pine, larch, Douglas-fir, and grand fir seedlings in some measure makes up for less abundant seed production. These species are able to become established under habitat conditions too severe for redcedar and hemlock.

TABLE 29.—*Composition of residual stand 10.6 inches d. b. h. and larger and species distribution of seedlings germinating in 6- to 8-year period following logging, on acre basis* [1]

Species	Trees left after logging		Seedlings germinating per acre	
	Number	*Percent*	*Number*	*Percent*
Western white pine	9.6	22	2,166	3
Western larch	3.2	7	1,327	2
Douglas-fir	1.2	3	290	
Grand fir	7.4	17	1,550	2
Western redcedar	8.3	19	28,170	36
Western hemlock	13.8	32	43,832	57
Other species	.1		63	
Total	43.6	100	77,398	100

[1] Data from 12 permanent sample plots.

SEEDLING ESTABLISHMENT

Ample seed supply and abundant germination by no means assure satisfactory regeneration. Adverse conditions of light, temperature, and moisture, particularly during the critical early season, may easily destroy an entire seedling crop. Even under generally favorable conditions, a considerable portion of the seedlings germinating are killed during the first few seasons by adverse weather and local soil conditions and by various biotic agents, particularly rodents, insects, birds, and fungi. On 15 cut-over areas in the western white pine type on which conditions are relatively favorable to seedling survival, 46 percent of all seedlings died in the first season and a total of 62 percent in the first three seasons (table 30). Losses dropped off rapidly after the first year, and it seems probable that the low mortality rates noted after the third year continued until competition due to increasing density in the seedling stand became an active factor.

TABLE 30.—*Seedling mortality of the 6 principal species on 15 cut-over areas, by years since germination*

Species	1 year	2 years	3 years	4 years	5 years	6 years	Total
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Western white pine	43	7	5	5	3	2	65
Douglas-fir [1]	43	9	8	0	3	2	65
Western larch [1]	46	8	7	3	2	1	67
Grand fir	32	10	8	6	4	0	60
Western hemlock	70	9	3	2	1	7	92
Western redcedar	44	8	8	4	4	6	74
Average	46	9	7	3	3	3	71

[1] Values for fifth and sixth years and total are approximate.

Because of the high initial losses, knowledge of the conditions affecting seedling survival and measures by which they can be modified is essential to the successful practice of silviculture. Such knowledge is of particular importance in the western white pine type, where the aim is to obtain reproduction stands not only adequate in total numbers but also containing sufficient proportions of the more desirable species. This was early recognized, and in 1913 Brewster [32] undertook a study

[32] BREWSTER, D. R., FACTORS GOVERNING NATURAL REPRODUCTION ON VARIOUS SITES. Working plan, 1913. Also BREWSTER, D. R., and LARSEN, J. A., STUDY OF FACTORS AFFECTING NATURAL REPRODUCTION, Progress report, 1916. Northern Rocky Mountain Forest and Range Expt. Sta. [Unpublished.]

of germination and early survival and development at three stations on the Priest River Experimental Forest. One station was on a northeast slope, one on a southwest slope, and the third on a dry bench. At each station the seed of six species, western white pine, ponderosa pine, western larch, Douglas-fir, western hemlock, and western redcedar, were sown on burnt mineral and natural duff surfaces in the open and on trenched and untrenched quadrats of duff surfaces in the shade of timber or heavy brush. The trenched plots, which were denuded of all vegetation, were established to determine whether removal of moisture from the soil by roots of trees and shrubs affected seedling survival under heavy shade. All plots were enclosed with screens of ½-inch mesh to keep out rodents. Air and soil temperatures, wind velocity, air humidity, and precipitation were recorded daily. At weekly intervals, soil moisture content was determined and counts of seedling germination were made. So far as possible, dead or dying seedlings were classified as to cause of death.

All the species tested were found best adapted, even in the initial seedling stage, to the habitats in which they commonly occur. Ponderosa pine was the only species to show satisfactory survival on the southwest slope; ponderosa pine, larch, and Douglas-fir all survived satisfactorily on the dry bench; and western white pine, redcedar, and hemlock proved best adapted for survival on the sheltered northeast slope. In general, survival was better on burned-over or denuded surfaces than on natural surfaces at all stations, a result at least partially due to the absence of other vegetation. Vegetative competition for moisture was shown conclusively to be a factor of considerable importance at the southwest and bench stations, where drought was the most active agent of mortality. Damping-off organisms were very active on all surfaces at the northeast station, and under shade and on duff surfaces at all stations, accounting for the majority of losses under these conditions. Frost-heaving and other winter losses were very heavy, particularly on the southwest slope and the bench, where snow cover afforded less protection in spring and fall. A few seedlings were killed, also, by insects and rodents. The rather small number of seedlings germinating and the lack of systematic replication prevented any critical analysis of losses according to mortality agent, species, and station.

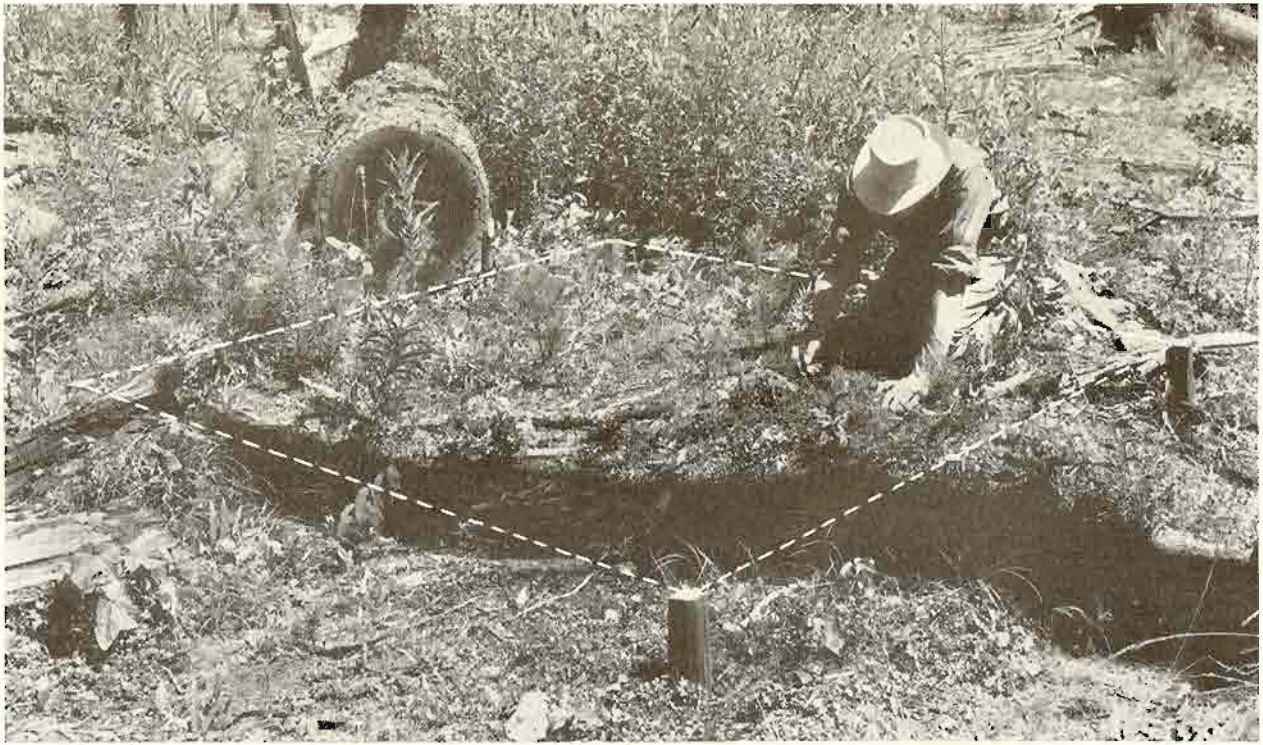
It is possible that, in spite of the protective screens and the relatively moist character of the 1913 growing season, losses due to insolation occurred on the drier sites, and that these were classified among fungus and drought deaths. It was not until 1916 that attention was first called in an American journal, by Hartley (*20*), to the fact that insolation often produces surface-soil temperatures high enough to destroy the cambium of tender young seedlings at the ground line. In any event Larsen (*37*), summarizing the survival data for publication in 1924 in connection with additional studies, called attention to the dangerous temperatures recorded on some plots, and, although no experimental data were available showing actual losses due to insolation, surmised that very high surface-soil temperatures on cleared and exposed flats and south slopes were causing injury to the seedlings of western white pine, redcedar, and hemlock.

Wahlenberg (*60*), studying the possibilities of reforestation by sowing seed in prepared spots, also contributed information on the nature and importance of various mortality agents affecting initial seedling

F270746

SEED TRAP USED IN STUDY.

The frame is 39.6 inches square (1/4000 acre) and 4 inches deep. A removable cover of coarse-mesh screen admits conifer seed but excludes rodents. Fine-mesh screen on the bottom keeps seed in.



F270741

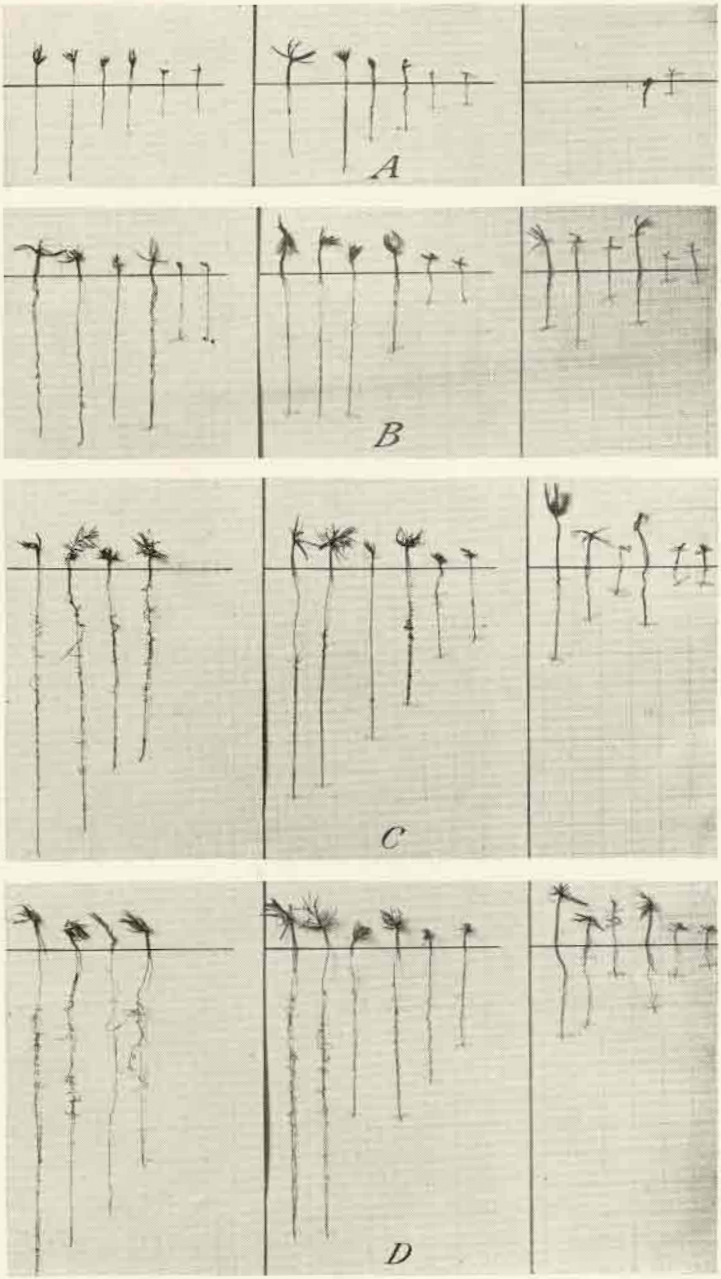
NATURAL REPRODUCTION QUADRAT

Dotted lines show boundaries of quadrat used in studying establishment of natural reproduction on cut-over areas.

F27239 (—272400)

EFFECT OF SHADE ON SEEDLINGS.

A, Slender, weak, and etiolated western white pine seedlings grown under full shade; *B*, stocky western white pine seedlings grown under full sun.



ROOT PENETRATION OF FIRST-YEAR SEEDLINGS.

Groups, left to right, taken from full-sun, part-shade, and full-shade stations, respectively, 1933. Each space represents 1 inch. Seedlings as grouped are, left to right, grand fir, Douglas-fir, western larch, western white pine, western redcedar, and western hemlock. Root penetration is shown as of (*A*) May 30, (*B*) June 30, (*C*) July 30, and (*D*) August 30. On May 30, only western white pine and western redcedar germinated under full shade.

survival. Germination and survival were observed on 300 prepared seed spots in tests conducted over the 6-year period 1916–21. During the first 2 growing seasons each seed spot was visited at 7- to 10-day intervals, germination noted, and seedling mortality recorded by cause. Survival was generally very poor. Most of the large seed sown were destroyed by rodents. Among the seedlings that did start, Wahlenberg records that by far the heaviest losses were caused by drought, and the next heaviest by cutworms. Frost heaving and fungi also caused heavy losses. Although Wahlenberg mentions that stones lying on surfaces exposed to the sun may attain temperatures injurious to growing tissues and possibly fatal to nearby seedlings, he did not list high surface-soil temperatures among the common agents of mortality. Probably surface temperatures were not particularly high on the steep north and northwest slopes he studied. Owing to the extensive nature of the tests, no instrumental records were made of soil moisture or surface-soil temperature conditions. In another study Wahlenberg (*61*) recorded surface-soil temperatures up to 145° F. in the open on an east slope. Such temperatures would quickly result in injury and death to succulent young seedlings.

More recently, Haig (*19*) has completed a study of the role played by various factors in the initial establishment of seedlings under measured environmental conditions. First-year mortality was studied at three stations on the Priest River Experimental Forest, all located on a large river flat representing severe to moderately severe conditions for western white pine. Although soil and general climatic conditions were identical throughout the series, the stations varied materially in microclimatic conditions owing to differences in the density of the residual stand. As control of overwood shade is one of the most effective tools of the silviculturist, it was reasoned that this arrangement offered the most promise of supplying useful and practical results. One station had been clear-cut; one had been partly cut, retaining a fairly heavy stand including a large number of small understory trees; the third was in a nearby uncut climax stand of great density.

Each station, enclosed by a high woven-wire fence, was equipped with rain gage, hygrothermograph, maximum and minimum air thermometers, soil thermometers, air and duff psychrograph, anemometer, and soil-water measuring equipment (geotome, soil cans, oven, balance, and duff hygrometer). Equipment used to measure light intensities were a stop-watch photometer with solio paper, Shirley thermopile, and Livingston black and white porous atmometer spheres. Seedling phytometers, both sealed and free, were employed. Soil temperatures were taken at the surface (the bulb barely covered with a light layer of soil or needles) and at levels 1 foot and 2 feet below the surface. Wind velocities were measured at the standard 8-foot level, and conversion factors to reduce the 8-foot readings to velocities at seedling level were obtained through a series of test runs with anemometer cups set 6 inches above soil level. Soil-moisture determinations were made at weekly to 10-day intervals. A cooperative Weather Bureau station at the Priest River Experimental Forest headquarters, within one-half mile of the study stations, furnished a 20-year record with which to compare the general character of weather conditions during the seasons of study.

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Causes of seedling mortality were studied at each station during the seasons of 1932 and 1933 by means of a series of prepared quadrats sown to western white pine, western larch, Douglas-fir, western hemlock, western redcedar, and grand fir (pl. 6). Natural duff, natural mineral soil, and burnt mineral soil were used in these installations, and some control quadrats were specially treated. Each type of surface was represented in duplicate or triplicate, to permit measurement of chance variation. On each quadrat sufficient seed was sown, on plats 16 to 20 inches square, to insure a sample of about 200 to 500 seedlings of each species with which to follow mortality by cause. Quadrats were examined at 2- to 10-day intervals, depending on the quantity and character of seedling mortality, and each dead seedling was classified as to cause of death after an individual examination. This diagnosis was strengthened by the instrumental records, which furnished concurrently an excellent picture of habitat conditions at the time of death. In addition 10 seedlings were carefully removed at weekly to 10-day intervals from special beds for determination of root penetration. The resulting data were used in conjunction with soil moisture measurements in rating the current effectiveness of drought as a cause of mortality. Table 31 summarizes the general character of the first-year losses during the 1932 and 1933 seasons.

Mortality began immediately after germination in late April or early May, while the soil was still thoroughly soaked by melting snow and spring rains. Early mortality was caused principally by biotic agents, namely, insects, birds, rodents, and fungi. Practically all took place when the seedlings were succulent and tender. The gradual hardening of seedling tissues and the drying out of the surface soil slowly brought about a cessation of mortality due to biotic agents. Later losses, beginning in late June and early July, were principally due to insolation and drought.

Losses Due to Biotic Agents

Fungi have already been shown to be the most destructive of the biotic agents (table 31), accounting for 24 percent of all deaths in the 2 years of the experiment, or about five times as many seedlings as were destroyed by insects and birds combined. Greatest mortality was in full sun and least in part shade. In general, losses from fungi did not vary significantly between the mineral surfaces. Fungi were much more active on duff than on mineral surfaces at both the part-shade and the full-sun station (table 32), though data were incomplete because of poor germination on duff surfaces. Fungi also were generally more active on all surfaces at the full-sun station than at the part-shade station during the two years of the study. This seems to indicate that from the standpoint of fungus activity the higher temperatures on the full-sun area, particularly on duff surfaces, more than compensate a somewhat shorter season due to earlier drying. Under full shade, where surface temperatures do not vary so markedly between duff and mineral surfaces, losses from fungi were irregular, being higher on duff in 1932 and much higher on mineral soil in 1933.

TABLE 31.—*Causes of first-year seedling mortality of the six principal species, from prepared quadrats under 3 degrees of light, 1932–33*

Station	Fungi	Insects and birds	Insolation	Drought	Total
	Percent	*Percent*	*Percent*	*Percent*	*Percent*
Full-sun	28	9	46	8	91
Part-shade	19	3	20	4	46
Full-shade	25	3	0	42	70
Average	24	5	22	18	69

TABLE 32.—*First-year seedling mortality caused by fungi on duff and natural mineral surfaces, on prepared quadrats, in percent of total germination, 1932–33*

Station, surface material, and year	Western white pine	Douglas-fir	Western larch	Grand fir	Western hemlock	Western redcedar	Average
Full-sun:							
Duff:	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
1932	46						46
1933	72	97	96	100			91
Mineral soil:							
1932	24						24
1933	32	33	14	23			26
Part-shade:							
Duff:							
1932	18	22				32	24
1933	25	37	70	38	51	51	45
Mineral soil:							
1932	10	17				11	13
1933	20	38	7	39	25	31	27
Full-shade:							
Duff:							
1932	15	12	19		12	44	20
1933	18	19	30	26	6	18	20
Mineral soil:							
1932	10	16	8		7	12	11
1933	44	66	61	55	18	37	47

Fungi attacked vigorously all the species commonly associated in the western white pine type. Losses by species from fungus attack were in some instances so varied as to suggest unequal distribution of conditions favorable to fungus development or of the more virulent fungus strains. The differences were not sufficiently consistent between stations or seasons to imply susceptibility differences among the species studied.

Losses due to insects also varied widely by species, year, and station. During both 1932 and 1933 they were materially higher at the full-sun station than at either of the others, the differences being greatest in western redcedar.

In contrast with insects and fungi, the birds that frequented the cut-over areas, and the climbing rodents such as mice, wood rats, and squirrels, seemed to be highly selective. Most of their damage was done to western white pine. Losses caused by birds were relatively light and were not recorded separately from insect damage. Rodents were successfully excluded from the full-sun and part-shade stations by fencing and other protective measures. Though greatly reduced in number at the full-shade station by poisoning and trapping, rodents destroyed 36 percent of the western white pine seedlings there in 1932, with very little damage to seedlings of other species on immediately adjacent plots.

It is impossible to judge how fairly the biotic losses observed in this study represent biotic losses in natural seedlings stands, which are less dense than those on the study plots. Undoubtedly, however, biotic agents are a potent if somewhat erratic factor in initial mortality of seedlings in the western white pine type.

Losses Due to Physical Agents

INSOLATION

Insolation, causing injuriously high surface-soil temperatures, was the most important physical agent of mortality encountered in this study. It also played a part in creating soil-moisture deficiencies responsible for drought losses. High temperatures are produced by direct exposure to strong sunlight as soon as a thin layer of topsoil or duff is dry, and cause stem lesions at the ground line, killing many of the seedlings. Insolation accounted for five to six times as many seedling deaths as drought at the full-sun and part-shade stations (table 31). No heat losses occurred at the full-shade station, where soil temperatures never went above 89° F.

TABLE 33.—*First-year seedling mortality on mineral soil caused by physical factors, in percent of those seedlings surviving biotic losses, 1932–33*

Physical factors and tree species	Full-sun station			Part-shade station			Full-shade station		
	Unburned soil	Burned-over soil	Weighted average	Unburned soil	Burned-over soil	Weighted average	Unburned soil	Duff	Weighted average
Insolation:	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
Western white pine	55	66	60	6	22	14	------	------	------
Douglas-fir	78	84	81	9	19	14	------	------	------
Western larch	74	79	75	16	32	24	------	------	------
Grand fir [1]	91	86	88	6	12	8	------	------	------
Western hemlock	62	56	58	33	41	37	------	------	------
Western redcedar	71	80	75	38	35	37	------	------	------
Average, all species	72	75	73	18	27	22	------	------	------
Drought:									
Western white pine	8	6	7	(2)	1	(2)	47	34	41
Douglas-fir	6	4	5	1	1	1	16	20	17
Western larch	4	4	4	1	3	2	90	94	93
Grand fir [1]	1	2	1	0	0	0	8	24	16
Western hemlock	37	43	39	16	19	18	93	97	95
Western redcedar	28	20	24	2	10	6	51	68	60
Average, all species	14	13	13	3	6	5	51	56	54
All physical factors: [3]									
Western white pine	63	72	67	6	23	14	47	34	41
Douglas-fir	84	88	86	10	21	15	16	20	17
Western larch	78	83	80	17	35	26	91	95	93
Grand fir [1]	92	88	89	6	12	8	8	24	16
Western hemlock	100	100	100	49	60	55	93	97	95
Western redcedar	100	100	100	49	45	43	52	68	60
Average, all species	86	88	87	21	33	27	51	56	54

[1] Values are for 1933 only.
[2] Trace—less than 0.5 percent.
[3] Including frost and miscellaneous other factors.

A much clearer idea of the extent of insolation and drought deaths is given if deaths due to biotic causes, which occur early in the season, are subtracted from the total number of seedlings produced, and the number killed by physical factors is expressed in terms of the residual value. This is necessary if species differences are to be compared fairly. Obviously, for example, if 90 percent of the seedlings of one species are killed by biotic agents early in the season only 10 percent at most can be killed by physical factors. Seedling mortality caused by physical factors is summed in terms of total germination less biotic mortality in table 33.

Insolation was by far the most important physical agent of mortality at the full-sun station, and drought the only important one at the full-shade station. Insolation caused the death of four to six times as many seedlings as drought on the cut-over areas, killing 73 percent of the seedlings surviving biotic losses at the full-sun station and 22 percent at the part-shade station. From the effect of insolation at the part-shade station, where the action of this agent is less obscured by drought deaths occurring during the same period, it is clear that grand fir, Douglas-fir, and western white pine are relatively resistant to high surface-soil temperatures, western hemlock and western redcedar are distinctly less so, and western larch is intermediate between these two groups. The differences have been tested statistically and found significant.

The influence of insolation depends to some extent upon cortical development of the stem; early hardening of external stem tissue undoubtedly increases resistance to injury. That seedling tissues harden when subjected to severe temperatures is shown by the coarse woody appearance of seedling stems at the full-sun station in midseason as compared with seedling stems under part or full shade (pl. 7). Hardening of the cortex undoubtedly explains why the larger and sturdier seedlings characteristic of some species are able to survive at all in the extremely high temperatures recurring day after day on the full-sun area and on the more exposed portions of the part-shade area. As previously stated, temperature conditions are particularly severe in the western white pine region, scanty summer precipitation and prevailingly clear, cloudless weather resulting day after day in extremely high surface temperatures capable of destructive injury to unprotected plant tissue.

Numerous investigators (*2*, *5*, *20*, *26*, *49*, *55*, *59*) have pointed out the damaging effect of temperatures exceeding approximately 120° F. on green plant tissue. The degree of injury varies, of course, with age and species of seedlings. Baker (*2*) found that damage may appear when internal temperatures go as high as 117° and may become common when they go above 130°; and that above 150° few young seedlings survive. Table 34 summarizes the occurrence of high temperatures during the growing seasons of 1932 and 1933. In the surface soil at the full-sun station temperatures of 120° or more occurred on 48 days during 1932 and 52 days during 1933, and temperatures of 135° or more occurred on 16 days in 1932 and 20 days in 1933. Daily maxima as high as 144° in 1932 and 150° in 1933 were recorded on mineral surfaces at this station. As a result, seedlings succumbed rapidly to heat girdling at the ground line, redcedar disappearing entirely by the end of July and hemlock by the end of August, and the number of live seedlings of the more resistant species was

seriously depleted. At the part-shade station, soil temperatures went to 120° or higher on only 13 days in 1932 and 16 days in 1933, and never reached 135°.

TABLE 34.—*Effect of shade on surface soil temperature on mineral quadrats, by months, 1932–33*

Station and month	Days on which temperatures were—				Daily maximum temperature			
	120° F. or higher		135° F. or higher		Monthly average		Highest	
	1932	1933	1932	1933	1932	1933	1932	1933
Full-sun:	*Number*	*Number*	*Number*	*Number*	*°F.*	*°F.*	*°F.*	*°F.*
May	0	0	0	0	87	82	104	94
June	4	2	0	0	101	100	128	126
July	22	26	7	8	128	129	144	146
August	22	24	9	12	125	126	144	150
Total or seasonal	48	52	16	20			144	150
Part-shade:								
May		0		0		72		89
June		0		0		85		106
July	4	11	0	0	108	113	131	130
August	9	5	0	0	107	105	127	125
Total or seasonal	13	16	0	0			131	130
Full-shade:								
May								
June		0		0		64		76
July	0	0	0	0	72	73	82	88
August	0	0	0	0	75	75	89	88
Total or seasonal	0	0	0	0			89	88

TABLE 35.—*Effect of surface-soil material on surface-soil temperatures at full-sun station, by months, 1932–33*

Month and surface soil material	Days on which temperatures were—				Daily maximum temperature			
	120° F. or higher		135° F. or higher		Monthly average		Highest	
	1932	1933	1932	1933	1932	1933	1932	1933
May:	*Number*	*Number*	*Number*	*Number*	*°F.*	*°F.*	*°F.*	*°F.*
Duff	8	9	0	4	111	109	134	144
Natural mineral	0	0	0	0	87	79	104	94
Burned-over mineral	0	0	0	0	82	80	93	91
June:								
Duff	17	23	11	17	129	129	155	152
Natural mineral	4	2	0	0	101	101	128	126
Burned-over mineral	3	1	1	0	97	97	136	124
July:								
Duff	28	30	24	25	145	144	160	158
Natural mineral	22	26	7	8	127	129	144	146
Burned-over mineral	21	27	9	21	129	135	151	148
August:								
Duff	24	25	20	22	138	137	156	161
Natural mineral	22	24	9	12	125	126	144	150
Burned-over mineral	24	25	19	17	132	130	151	152
Total or seasonal:								
Duff	77	87	55	68			160	161
Natural mineral	48	52	16	20			144	150
Burned-over mineral	48	53	29	38			151	152

Surface temperatures vary greatly according to the nature of the surface soil. Table 35 gives temperatures on duff, natural mineral, and burnt mineral surfaces at the full-sun station. Duff temperatures

were particularly severe, as the light, porous character of the organic materials permits early surface drying and more rapid absorption and dissipation of heat. In May the only killing temperatures recorded occurred on duff surfaces. In the period May to August, inclusive, maximum temperatures of 120° F. or more occurred on duff 77 days in 1932 and 87 days in 1933, and on natural mineral surfaces 48 days in 1932 and 52 days in 1933. Burnt mineral surfaces have slightly higher temperatures than natural mineral, their darker color causing greater absorption of heat. The effect of surface material is best shown by number of days with temperatures of 135° or more. In 1932 and 1933 the number of days with such temperatures averaged 44 per year more on duff and 16 per year more on burnt mineral than on natural mineral surfaces.

On the cut-over areas, i. e., the full-sun and part-shade stations, this quicker surface drying, combined with a greater range in daily temperature extremes and increased danger from both frost and insolation, made duff surfaces extremely hazardous for young seedlings. Not a single seedling survived the first season on duff on the full-sun area, and very few survived on the less sheltered portion of the part-shade area.

In an experiment by Larsen (*37*) the findings were similar. Table 36, recompiled from his data, shows distinctly better survival on mineral than on duff surfaces.

TABLE 36.—*Seedling survival,*[1] *2 years after sowing, in relation to surface-soil material*

Surface-soil material	Western white pine			Western larch	Engelmann spruce	Average all species
	Test 1	Test 2	Average			
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Duff; Mixed duff and rotten wood	8	1	4	2	0	2
Partly burned duff; Charcoal and partly burned duff	31	----------	----------	----------	----------	----------
Charcoal and ashes; Deep, loose ashes	28	23	26	7	15	16
Natural mineral	29	[2]3	16	9	23	16

[1] In terms of total numbers of seed sown. After Larsen (*37*). Test 1, western white pine, was in 1918; test 2 in 1920.
[2] Fungus present.

DROUGHT

Drought, the second most important physical cause of seedling mortality, operates directly through the unbalance between soil moisture and root penetration, a circumstance that explains the paradox of heavy drought mortality on the relatively cool, moist, full-shade area (table 33). This situation is illustrated in figure 11, which shows graphically the progress of surface-soil drying on each of the three areas in the 1933 season. Maximum and minimum root depths at various times are shown for western white pine, one of the deeper-rooted species, and western hemlock, the shallowest-rooted species. Soil drying in the upper layers, of great importance in initial survival, is shown to take place primarily from the surface downward.

Although soil drying on the full-sun area was rapid and relatively deep, this was compensated in part by deeper root penetration, particularly by the more resistant species, western white pine, Douglas-fir,

western larch, and grand fir. In 1933, for example, the soil on this area had dried to a depth of 7 inches by late August, but seedlings of these species in some cases had roots penetrating 11 inches or more at this time, and relatively few of them died of drought. The shorter-rooted species were unable to maintain a favorable balance of root penetration and soil moisture and consequently suffered heavily. Drought losses began as soon as the soil moisture content dropped below the wilting coefficient in the layer in which seedlings were rooted, about June 25, and resulted immediately in drought deaths of hemlock and redcedar.

At the part-shade station (figure 11), the root-penetration balance in 1933 was favorable to all species except redcedar and hemlock. Surface drying, beginning about June 25, killed a few short-rooted hemlock on mineral surfaces, but was relieved by rains on June 28 and 29. About July 6, surface-soil drying again began to kill some redcedar and many hemlock on exposed quadrats, and this drying lasted until the fall rains began. Only a few short-rooted individuals of other species were killed by drought in 1933.

At the full-shade station, although surface drying began much later in the season and reduced soil moisture to or below the wilting coefficient to a maximum depth of only 3 inches, drought losses were heavy because of shallow root penetration of all species. Low light intensity and unfavorable soil and air temperatures, though not direct causes of mortality, probably had an important part in preventing seedlings from growing vigorously and hence from becoming drought resistant.

Drought losses at the full-sun and part-shade stations, particularly the former, would have been relatively higher if insolation had not previously killed large numbers of redcedar and hemlock. A few quadrats at the full-sun station were shaded by screens, which prevented lethal surface-soil temperatures. Soil-moisture conditions were substantially the same on both shaded and unshaded quadrats, except that the former dried out a little more slowly as the season progressed. On the shaded quadrats drought ranked second to biotic factors as a cause of mortality, having an especially severe effect on the shorter-rooted species. Apparently drought may play a much more important role on areas where insolation is not an agent of mortality. Results of a study made in 1934 show that on north slopes drought tends to be the most important physical agent of mortality.

The relative susceptibility to drought of the seedlings of various species tested at the river-flat stations is shown by table 37. In full sun and under part shade, as nearly as can be judged from the 1933 records, the four hardier species do not differ significantly in resistance. Western redcedar and western hemlock again form a more susceptible group. Redcedar is definitely less susceptible than hemlock, owing at least in part to its slightly but consistently deeper root penetration. Under full shade the species differ more sharply with regard to drought resistance. Here the extremely weak root penetration of western larch makes this species the equal of hemlock in susceptibility. Douglas-fir and probably grand fir were the least susceptible. In the intermediate group of western white pine and redcedar, white pine is significantly the less susceptible. Drought resistance was closely linked in every case to depth of initial root penetration. Plate 8 shows differences in root penetration between species, stations, and times of season.

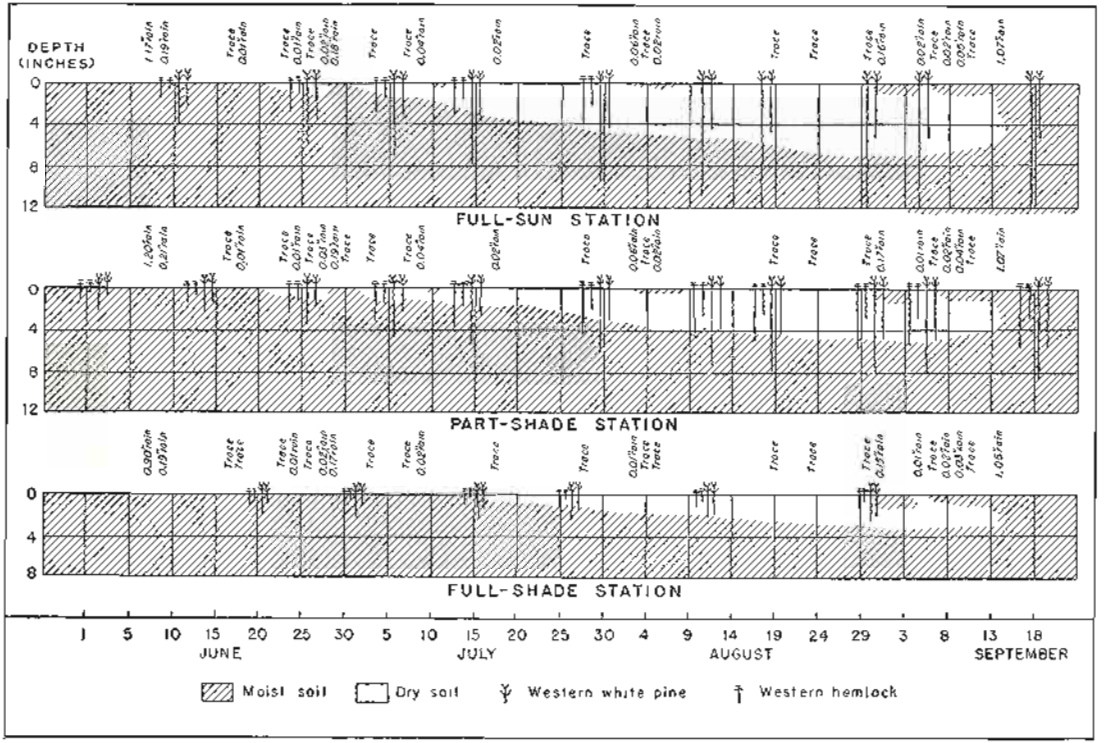


FIGURE 11.—Root penetration and progressive soil drying in 1933. "Dry soil" is soil dry to or below the wilting coefficient, approximately 16 percent by oven-dry weight.

TABLE 37.—*First-year drought mortality of seedlings of six principal species surviving biotic losses, under different light conditions, 1932–33*

Species	Full-sun station	Part-shade station	Full-shade station
	Percent	*Percent*	*Percent*
Western white pine	7	(1)	41
Douglas-fir	5	1	17
Western larch	4	2	93
Grand fir [2]	1	0	16
Western redcedar	24	6	60
Western hemlock	39	18	95
Average [3]	16	5	61
Standard error	±2.2	±2.1	±4.8

[1] Less than 0.5 percent.
[2] Records for 1933 only.
[3] Excluding grand fir.

The high seedling mortality consistently observed on exposed duff surfaces, although caused mainly by high temperatures, is due in lesser degree to unfavorable moisture conditions. The rapid fluctuation in moisture content of duff kills many newly germinated seedlings before their roots can become established in mineral soil under the duff. The moisture content of the mineral soil under the duff is about the same as that of exposed mineral surfaces, and once the seedling roots are established in the underlying mineral soil, the survival on duff tends to be nearly the same as on mineral surfaces under shade or on north slopes, where insolation losses are few. This is indicated by permanent sample-plot records (table 38) from areas on which conditions were generally more favorable for seedling establishment than on the severe river-flat areas of Haig's study. Differences in survival between surfaces were not very pronounced. Although not susceptible of statistical analysis, because of the irregular character of the basic data, these sample-plot records indicate that of the three kinds of surface listed, establishment is best on mineral soil, poorest on rotten wood, and intermediate on duff.

TABLE 38.—*Seedling survival of principal species on four cut-over areas 5 years after cutting, in percent of all seedlings produced*

Surface soil material	Western white pine	Grand fir	Western hemlock	Western redcedar	Average	
					Hardier species [1]	Susceptible species [2]
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Duff; mixed duff and humus; scorched duff	34	45	8	26	43	17
Rotten wood	28	43	8	10	35	9
Natural mineral	41	55	8	38	51	23

[1] Record includes western white pine, grand fir, and a few Douglas-firs and western larches. Data insufficien to list species separately by surface soil material.
[2] Western hemlock and western redcedar.

SILVICULTURAL CONTROL

The silviculturist can in great measure control the abundance of natural reproduction by manipulating the distribution and density of the residual stand. On severe sites, in general, most abundant

regeneration is got by retaining a fairly dense residual stand, because such a stand reduces insolation and maintains a favorable balance between root penetration and soil moisture. Such conditions not only eliminate high surface-soil temperatures and drought, the principal physical agents of initial mortality, but restrict biotic losses, and tend to produce high initial survival of all species. On sites where aspect largely prevents high surface-soil temperatures, regeneration is probably favored by retaining only a light residual stand or by clear cutting.

Obtaining the most desirable species composition in the seedling stand is often more difficult than obtaining adequate density. It can be promoted to some extent through control of overwood shade. Retention of fairly heavy residual stands on flats and southerly slopes tends, entirely aside from its effect on seed supply, to decrease the proportion of western white pine and its hardier associates and increase the proportion of western redcedar and western hemlock. Clear-cutting on severe sites, on the contrary, tends to reduce the proportion of western redcedar and western hemlock, as these species are far more susceptible to high surface-soil temperatures and drought than their associates, and to increase the proportion of western white pine, Douglas-fir, western larch, and grand fir. However, mortality losses in full sun on severe sites may be so heavy as to prevent adequate regeneration of any species.

On more sheltered sites, such as north slopes, available evidence indicates that given an adequate seed source, clear-cutting will produce the most desirable seedling stand, as regards both quantity and composition. On such sheltered sites losses due to high surface temperatures are largely eliminated and full-sun conditions favor establishment of western white pine. Drought, an active agent even on these sites, materially reduces the crop of more susceptible species such as redcedar and hemlock, although, under generally favorable conditions, an appreciable percentage of these species may be expected to survive.

One outstanding practical limitation to the control of composition by varying the density of overhead shade lies in the fact that it is apparently impossible except within narrow limits to encourage western redcedar, a commercially valuable species, without also encouraging western hemlock, a species of low commercial value, or to encourage the highly valuable western white pine without also encouraging the commercially inferior grand fir. These limitations indicate the probable necessity of employing cultural methods, such as weeding, if composition of the seedling stands is to be effectively controlled.

EARLY DEVELOPMENT

The problems of natural regeneration do not end with successful seedling establishment. Seedling stands may originate under conditions unfavorable to satisfactory growth and, as has been pointed out, composition of the seedling stand can be controlled to a limited extent only. The character of the soil, the seed source, density of overhead shade, and relative aggressiveness of the associated species, particularly during early life, all affect the make-up of the stand at maturity. This period of early development, roughly the first 30 years, is important to the silviculturist because rate of growth and species composition

can then be effectively controlled by cleaning and by regulation of overwood density.

Effect of Burned-Over Surfaces

The marked effect on early seedling development of burning off the layer of duff and litter from mineral soil has already been brought out with reference to the study made by Haig (*19*). During both seasons covered by that study, seedlings grew larger on burnt than on nearby natural mineral soil.[33] At the part-shade station, 2-year-old seedlings on burnt mineral soil were from 25 to more than 100 percent taller than seedlings on adjoining natural mineral surfaces, western larch showing the greatest difference. Microchemical tests revealed that burning made available a materially increased supply of several important mineral nutrients for at least 2 years after burning. Burning resulted in a slight to very marked increase in the quantity of active manganese, available magnesium, nitrate nitrogen, available phosphorus, and replaceable calcium. Available phosphorus was almost doubled, and the increase of replaceable calcium and nitrate nitrogen was even larger. The total carbon content was slightly reduced. The differences were considerably greater in the top 3 inches of the soil than at lower levels.

Seedling response to the greater supply of available nutrients continued to the end of the second growing season. At that time, at the part-shade station, the tops of western larch, a species particularly sensitive to habitat changes, had an average green weight of 1.64 gm. on burnt mineral as compared with 0.60 gm. on natural mineral surfaces. In general the top weight of all species combined was about twice as great on burned-over as on natural mineral surfaces. During the second growing season all species made markedly better leader growth on the burnt surface.

Other investigators (*1*, *13*, *22*, *27*, *56*) have consistently found the supply of available nutrients in the forest soil to be increased for at least a year or two by burning. Further investigation is needed, however, to determine the full and final effect of burning on seedling establishment and development. It is quite possible that losses through soil washing or changes in physical composition resulting from single or repeated fires more than outweigh the initial gain in soil fertility.

Effect of Overwood Density

Density of the overwood stand affects seedling development very materially from the first year or two on. Haig (*19*) found at the end of the second season that best seedling height growth had been made under part shade; western white pine averaged one-third taller than in full sun, Douglas-fir seedlings were twice as tall as in full sun, and western larch and grand fir made even larger relative gains. Growth as measured in green top weight of the last three of these species was also better under part shade than in full sun. Western white pine, however, was a marked exception, averaging 0.61 gm. in full sun on natural mineral surfaces, and 0.86 gm. on surfaces in full-sun that were slightly protected by low screens, but only 0.35 gm. under part

[33] Similar observations have been made by Brewster and Larsen (*37*). Also Sixth Annual Report of the Priest River Experimental Forest, Northern Rocky Mountain Forest and Range Expt. Sta. 1916. [Mimeographed.]

shade. Comparable data are not available for western hemlock and western redcedar, as seedlings of these species did not survive at the full-sun station.

After the first few years, western larch, lodgepole pine, Douglas-fir, and western white pine grow best under practically full-sun conditions. The marked effect of density of overwood on the growth of reproduction in these later years is illustrated in plates 5 and 6, of which all views were taken within 200 yards of each other on a cut-over area on the Kaniksu National Forest. The area represented is uniform in all respects except for density of the stand left after logging. On a nearly clear-cut portion (pl. 9, *A*), western larch and the few lodgepole pine trees present have made excellent growth and are the tallest, with western white pine next. These species make up practically all the dominant stand. Most of the grand fir and all the western hemlock and western redcedar are distinctly subordinate in height. Under partial shade [34] (pl. 9, *B*), western white pine, though not quite so tall as under practically full-sun conditions, forms a larger proportion of the dominant stand, and larch and lodgepole have made much poorer development. Grand fir and hemlock are both more prominent under partial shade than in the open. Under moderately dense shade (pl. 10, *B*), larch and lodgepole are practically absent and trees of other species have made poor growth. The relation between white pine and the more tolerant grand fir and hemlock has become reversed; the fir and hemlock are now the tallest. Under very dense shade (pl. 10, *A*), trees of all the species barely exist, as is illustrated by the white pine trees shown against the white sheets. Average heights of the white pine trees in this stand, and other stand data, are given in table 39. The general trends in the effect of overwood density on reproduction development shown by these data have been demonstrated on many other areas.

TABLE 39.—*Relation of overwood density to height and number of 16-year-old western white pine seedlings on portions of the Kaniksu National Forest*

Area	Residual overwood density (basal area per acre)	Average height dominant white pine seedlings [1]	Seedlings per acre	
			Western white pine	All species
	Square feet	*Feet*	*Number*	*Number*
A	26	6.7	3,480	4,449
B	59	2.6	5,720	7,920
C	95	1.6	5,360	15,880
D	150	.7	1,520	8,400

[1] The tallest seedling of this species on each 1/1,000-acre unit of area.

The effect of overwood and aspect upon the relative growth of associated species in the reproduction stand over a period of years is brought out by table 40. This table is based upon examinations of four cut-over areas, and shows changes in the composition of the dominant stand in intervals of 10 to 19 years, the second examination having been made 25 years after logging in each case. The proportion of western white pine in association with western hemlock, grand fir, and

[34] It is not intended to ascribe all the effects of an overwood on reproduction to shade alone. Degree of shade, in terms of light intensity, is only a convenient single measure of overwood density. Other things such as soil temperature and moisture content are affected by overwood density and in turn affect growth of reproduction.

a small quantity of larch and Douglas-fir remained approximately constant on the clear-cut northerly slopes and doubled on the open easterly slope. Under approximately 40-percent shade, on the shelterwood area, western white pine steadily lost ground in the 19 years between observations. The 25 percent lost in this period was absorbed by western hemlock, the principal associate in this stand, which proved a very aggressive competitor. The relative development of western white pine on clear-cut areas would be less favorable in reproduction stands containing larger percentages of larch or lodgepole pine, as these two species thrive best in full sunlight and distinctly outgrow western white pine in the early years of stand development.

TABLE 40.—*Composition of dominant stand, with respect to overwood condition and exposure at various intervals after logging*

Overwood condition and aspect	Period since logging	Western white pine	Western hemlock	Grand fir	Western larch	Douglas-fir	Trees per acre
	Years	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Number*
Shelterwood;[1] northerly aspect	7	71	9	11	9	0	3,500
	25	46	38	16	0	0	1,300
Clear-cut; northerly aspect	6	26	58	13	2	1	2,155
	25	24	63	8	5	0	1,950
Do	15	94	3	0	1	2	845
	25	90	[2] 5	----------	[3] 5	----------	345
Clear-cut; easterly aspect	15	37	45	12	[4] 6	0	825
	25	74	18	5	[4] 3	0	424

[1] About 40 percent shade.
[2] Includes some grand fir.
[3] Includes some Douglas-fir.
[4] Includes some lodgepole pine.

RELATIVE AGGRESSIVENESS OF SPECIES

A good measure of the relative aggressiveness of individual species in the western white pine type during the period of early development is the proportion of the total number of trees of each species that are in the dominant stand. Such data are furnished by table 41, based on 12 sample plots representing stands from 8 to 30 years of age. It will be noted that, within this range of ages, western larch and lodgepole pine form a much larger proportion of the dominant than of the total stand. The proportion of western larch in the dominant stand was 3 to 5 times that in the total stand, as measured in milacre and 4-milacre units.[35] White pine and Douglas-fir form approximately the same proportion of the dominant stand as of the total stand. Grand fir and western hemlock are less aggressive. Western redcedar is obviously the least aggressive, forming 7 percent of the total stand and having no part in the dominant stand. These figures, in which the time element is not represented, would be more significant if based on repeated measurements of these plots over a number of years.

This order of aggressiveness is maintained with little change in older stands, as is shown by table 42. Comparison of relative dominance of associated species in these stands is most clearly made by considering the values for dominant and codominant crown classes combined. Lodgepole pine and western larch are obviously the most aggressive. Wherever present, they are found principally in the

[35] Only the tallest and most vigorous tree on each unit was designated as a dominant. These estimates consequently take into account both size and distribution over the area. Classifying trees by the usual system, i.e., as dominant, codominant, intermediate, and suppressed, is not practicable in very young stands.

dominant stand, not being sufficiently tolerant to survive long in a suppressed or even an intermediate position. It will be noted that hemlock and grand fir are transposed from the order given in table 41. The indicated differences in aggressiveness between these species are small, however, and probably not significant. Western redcedar is shown to be the least aggressive species, forming a negligible proportion of the upper two crown classes in second-growth stands.

TABLE 41.—*Relative aggressiveness of individual species in stands 8 to 30 years old, on 12 sample plots, as measured by dominance*

Species	Composition of total stand [1]	Composition of dominant stand [2] by—	
		Milacre units [3]	4-milacre units [4]
	Percent	*Percent*	*Percent*
Lodgepole pine	1	4	8
Western larch	6	20	33
Western white pine	44	50	38
Douglas-fir	3	8	3
Grand fir	20	16	12
Western hemlock	17	6	5
Western redcedar	7	1	0
Other species	2	0	1
Total	100	100	100

[1] All trees 0.6 foot tall and taller.
[2] Including only tallest and most vigorous tree on each area unit as indicated.
[3] A milacre unit is 6.6 feet square and includes 1/1000 acre.
[4] A 4-milacre unit is 13.2 feet square and includes 1/250 acre.

As implied above, relative dominance is also an excellent measure of tolerance. The tolerance ratings given to the associated species in the western white pine type on page 14 are almost identical with the dominance ratings given here. It has been found consistently that early dominance and rate of growth vary inversely with relative tolerance. Intolerant species must make rapid initial growth to maintain themselves in the stand. Tolerant species, on the other hand, make slower growth in early life, but, as has already been brought out, progressively form a more prominent part of the stand as time goes on and eventually largely dominate it.

TABLE 42.—*Relative aggressiveness of individual species in stands 32 to 100 years old* [1] *as measured by representation in different crown classes*

Species	Dominant class	Codominant class	Intermediate class	Suppressed class	Dominant and codominant class	Basis, trees
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Number*
Lodgepole pine	44	30	14	12	74	366
Western larch	30	26	27	17	56	1,212
Western white pine	16	19	27	38	35	8,924
Douglas-fir	8	15	25	52	23	1,089
Western hemlock	5	9	27	59	14	2,812
Grand fir	2	6	14	78	8	3,584
Western redcedar	0	2	10	88	2	1,445

[1] On 68 sample lots. All trees 1 inch d. b. h. and larger are included.

Records from a large number of permanent sample plots in stands from 30 to 100 years of age show only slight changes in species composi-

tion within intervals of 10 or 20 years. Such changes as do occur are irregular and are largely due to mortality, which for various reasons may hit one species harder than another during any particular period.

The frequently expressed opinion that under favorable conditions western white pine will readily outgrow its competitors is not supported by the evidence available. White pine apparently is hard pressed by its aggressive and fast-growing associates, and even under favorable conditions may barely hold its own. Assuming adequate protection, the only certain way of getting a satisfactory proportion of western white pine or any other desired species in the mature stand is to obtain a good representation of that species in the seedling stand and then assist its development by cultural methods applied principally during the early life of the stand. During the first 30 years in the life of the stand, species composition is relatively plastic and can be modified materially by changing the density of residual overwood and by weeding or thinning.

REGENERATION METHODS

As brought out in the section reviewing practices and investigations, diversity of forest conditions, gradual accumulation of specific silvical information, and pressure of economic considerations have led to application in the western white pine region of three of the four high-forest regeneration methods commonly recognized in the United States (*3*, *21*, *57*). Clear-cutting, seed-tree, and shelterwood methods have been applied rather extensively (pls. 11 and 12), the true selection method hardly at all. Many cuttings have also been made on a logger's selection or zero-margin selective basis, difficult to classify under standard regeneration methods.

The 30 years during which cutting has been carried on under technical supervision in the western white pine forests is too short a time for conclusive trial of any method. In particular, on few of the areas cut on a shelterwood or selective plan has sufficient time elapsed for a second cut to have been made. Experience gained on national-forest cuttings and specific information gained from research have, however, furnished a basis for an appraisal of regeneration methods applicable in the type.

The research basis includes results of a study of natural reproduction on 30 of the earlier cuttings, selected as representative of different methods,[37] detailed observations of the establishment and early development of natural reproduction on some 72 permanent plots sampling a wide range of conditions, and studies of seed supply, germination, initial establishment, and early development reported in this publication. On this basis a comparison of the four standard regeneration methods with reference to the western white pine type is made in table 43.

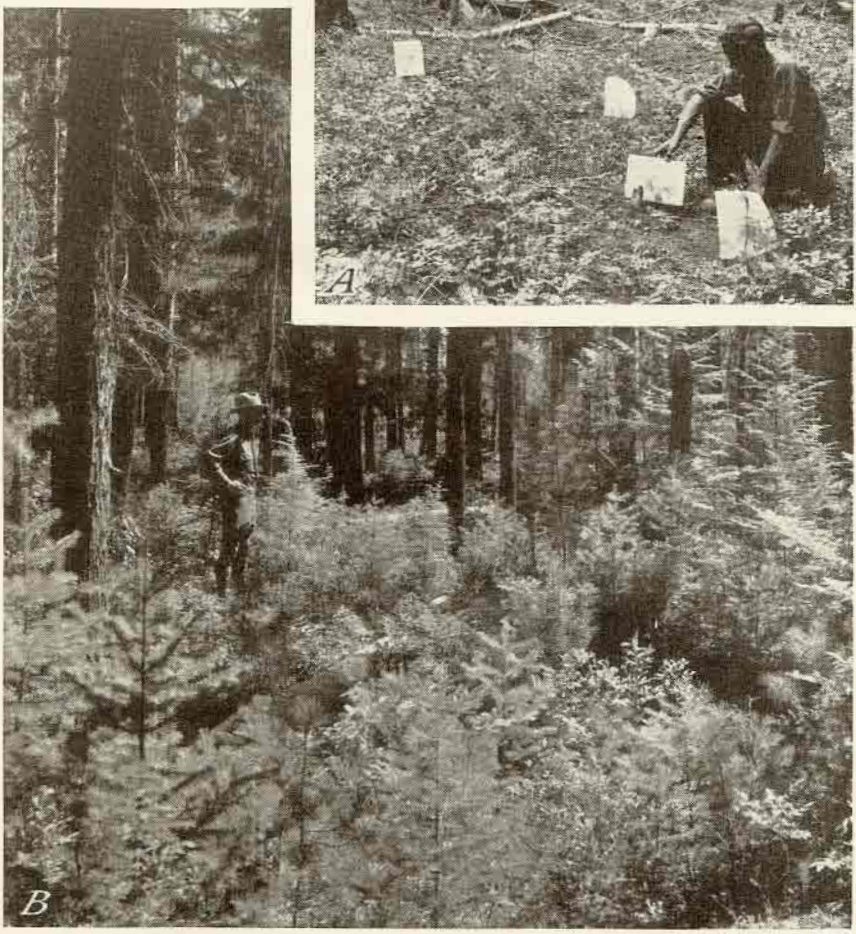
Experience and study have definitely shown that the forests of this type are too diverse, and the necessity for compromise between economic and silvicultural aims too pressing, for any one regeneration method to be practiced to the exclusion of all others. Selection of the method to use on any given area should be based on careful, rational appraisal of economic and silvicultural factors.

[37] HAIG, I. T., and WELLNER, C. A. NATURAL REPRODUCTION FOLLOWING LOGGING IN WESTERN WHITE PINE. Northern Rocky Mountain Forest and Range Expt. Sta. 1937. This unpublished manuscript has been drawn upon freely for information on the results of past practices.

F350685—350684

EFFECT OF LIGHTER OVERWOOD DENSITY ON REPRODUCTION.

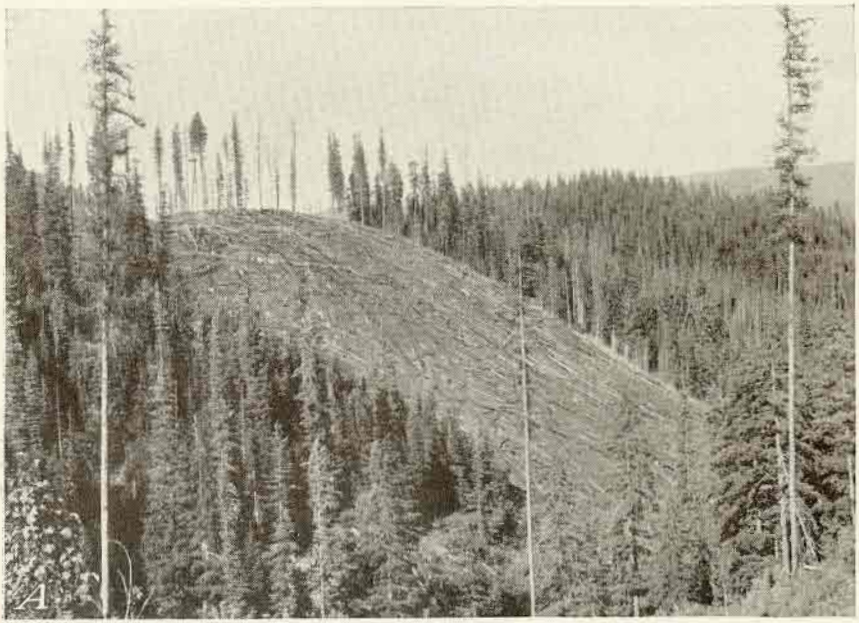
Development of reproduction as affected by the very light and moderate density of residual overwood in a seedling stand about 16 years old on the Kaniksu National Forest: *A*, Very light overwood; *B*, moderate overwood.

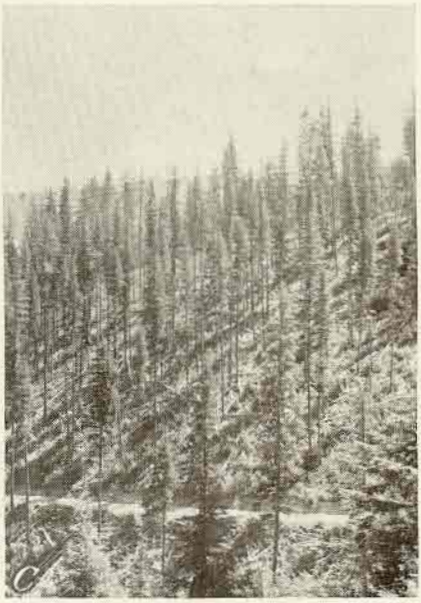


F311737

EFFECT OF HEAVIER OVERWOOD DENSITY ON REPRODUCTION.

Development of reproduction as affected by moderate density and full density of residual overwood in a 16-year-old stand: *A*, Dense overwood; *B*, moderately dense overwood.

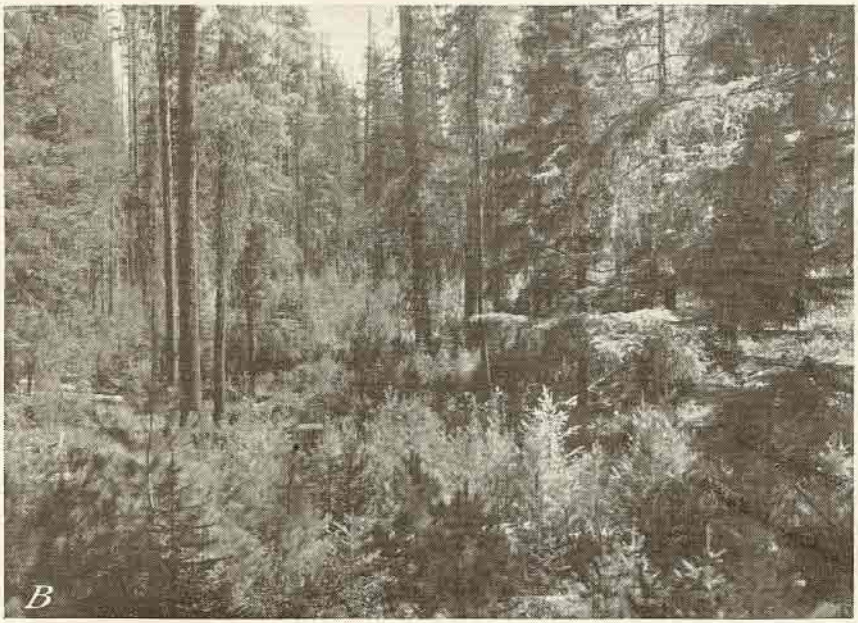




F351762—336547—298530

REGENERATION UNDER DIFFERENT TREATMENT.

A, A clear-cutting on which all merchantable timber was removed and residual stand, which was defective and of no value, felled and broadcast burned, and the area planted; *B*, vigorous natural reproduction, principally of western white pine, on strip clear-cut 26 years before, similar to that in *A*; *C*, seed-tree cutting showing western white pine seed trees.



F351763—350700

SHELTERWOOD TREATMENT.

A, Shelterwood strip of western white pine seed trees in combination with alternate clear-cut strips; *B*, natural reproduction 10 to 15 years old under a shelterwood.

Clear-Cutting

The essential feature of the clear-cutting method of regeneration is removal of the whole stand, or of the whole stand with the exception of seed blocks or strips, in a single cut (pl. 11). Reproduction comes from seed produced by nearby uncut timber or seed present on the area at the time of cutting; or the area, if large, may be planted.

As previously stated, this method was employed between 1909 and 1912 on the Kaniksu and Coeur d'Alene National Forests. Several areas on the Kaniksu were cut over by what was termed a clear-cut and seed-block method. They were clear cut except for uncut seed blocks from 2 to 20 acres in extent and from 250 to 1,300 feet apart, and complete reliance for reproduction was placed on natural seeding. One of the areas that restocked most successfully, the Beardmore, had an established stand per acre 14 years after cutting of 2,400 western white pine and 2,900 other seedlings, including an abundance of western redcedar. Individual specimens of the more rapidly growing species were 18 feet high, and 1,000 seedlings per acre, 87 percent of them western white pine, were more than 4.5 feet high.

Another of these cuttings, located on the large exposed Jurgens Flat, illustrates the need for a nearby seed source and the unfavorable effect of a severe site. Here, even 20 years after cutting, regeneration was not satisfactory at distances of more than 400 feet from the nearest seed block. Absence of satisfactory regeneration at greater distances from seed blocks was attributed partly to insufficient dissemination of seed and partly to lack of the protecting influence of standing timber. In general the results obtained with the clear-cut and seed-block method were only partially satisfactory, principally because (1) many of the areas clear cut were too large to be reseeded satisfactorily by natural dissemination from uncut blocks, (2) many of the sites thus cut over were too severe for successful seedling survival under full-sun conditions, and (3) seed in the duff was destroyed in broadcast burning or was not abundant enough to supplement adequately the seed disseminated by the trees left standing.

Where clear-cutting was restricted to strips 300 to 450 feet wide running at right angles to the topography and separated from each other by uncut strips about 150 feet wide, as was done between 1909 and 1912 on the Coeur d'Alene Forest, the land reforested in general promptly and abundantly, principally to western white pine. Plate 11, *B* shows a successfully regenerated clear-cut strip on the Isaac Sands sale of 1910. In 1934, examination of three clear-cut strips on this sale area showed that trees 0.6 inch d. b. h. and larger numbered 2,150 per acre. Of this total about 850 were in the dominant and codominant crown classes, which include nearly all trees of future importance in the stand. Approximately 70 percent of these dominants were western white pine. A few of these early Coeur d'Alene strip cuttings failed to regenerate satisfactorily, because of adversity of site. That south slopes and other less favorable sites often do not regenerate satisfactorily after clear cutting has been observed repeatedly. The influence of aspect is strikingly illustrated by the fact that on the Thompson-Nelson sale area, 15 years after the cutting, western white pine seedlings 0.5 foot or more in height totaled 5,400 per acre on a strip facing north and only 165 per acre on one facing south.

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TABLE 43.—*Comparison of regeneration methods applicable in the western white pine type*

Item	Clear-cutting	Seed tree	Shelterwood	Selection
Kind of stands in which best applied.	(1) Even-aged stands composed principally of merchantable trees. (2) Defective, overmature stands, only small portions of which are or will ever be merchantable, as old stands consisting largely of defective hemlock and grand fir.	Even-aged stands composed principally of merchantable trees, as stands from 120 to 200 years of age dominated by mature white pine.	(1) Well-stocked stands containing many trees of merchantable species but less than merchantable size. (2) Stands containing fair number of sound trees of species unmerchantable at the time of cutting but merchantable possibly later.	Partial application possible in uneven-aged stands containing advance reproduction, immature trees (especially redcedar), and merchantable trees. Here one or two selection cuttings could be made to advantage, even though it might not be possible to continue them.
Aspects to which best suited.	North, east, and less exposed west slopes, where white pine usually makes relatively better growth than its principal competitors, hemlock and grand fir.	North and east slopes and the less exposed west slopes and flats.	Any slope, though on north and east slopes the shelterwood must be sparse to permit reproduction of desirable composition.	Any slope, though on north and east slopes white pine reproduction is likely to be sparse.
Number of cuttings required and length of regenerative period.	One cutting. Regeneration period usually 1 to 10 years. Regeneration of any adjacent areas left uncut to produce seed is delayed until a second cut is made.	One major cutting. Seed trees may be removed by a second cutting if economically practicable. If left uncut, few are likely to survive until the new stand is cut. Regeneration period 1 to 10 years.	At least a seed cutting and a removal cutting. In intensive application, three or more cuttings. Regeneration period 1 to 40 years, depending on number of cuttings.	Number of cuttings indefinite. Regeneration more or less continuous.
Class of trees left after cutting.	None left, except blocks or strips of timber reserved where necessary for reseeding.	Thrifty, vigorous, full-crowned dominants or codominants, principally western white pine, selected for seed productivity and windfirmness; of merchantable size, usually 16 to 24 inches d. d. h.	(1) At least as many selected seed trees as in seed-tree cutting, principally western white pine; (2) thrifty, vigorous trees of merchantable species but less than merchantable size; (3) sound trees of species unmerchantable at time of cutting but possibly merchantable later.	All trees not selected as economically, silviculturally desirable for immediate cutting, both merchantable and unmerchantable.
Form of forest produced	Even-aged	Even-aged	Even-aged, or of not more than two or three age classes.	Uneven-aged.
Seed source	Nearby uncut trees and seed stores in duff at time of cutting. Seed in duff seldom alone sufficient. Supply usually ample if clear cuttings not more than 400 feet wide. Larger areas usually must be planted.	Selected seed trees. Only enough trees reserved to produce the quantity of seed estimated as necessary for adequate regeneration. Usually from 2 to 6 white pine seed trees per acre are reserved plus a few of other species.	Reserved trees, which are sufficiently numerous to insure an ample seed supply.	Reserved trees, producing an abundance of seed.
Abundance and species of reproduction usually resulting.	Good reproduction of white pine, Douglas-fir, larch, and grand fir where seed source is ample. Reproduction of hemlock and redcedar relatively poor except on better sites.	Good reproduction of white pine, larch, grand fir, and Douglas-fir. Hemlock and redcedar sparse except on slopes favorable to these species, as most north slopes.	Good reproduction of all species common in type except larch. Hemlock, grand fir, and redcedar very abundant.	Reproduction abundant but principally of hemlock, grand fir, and redcedar.

Economic considerations...	Clear cutting, usually followed by broadcast burning, is the cheapest method of restoring to productivity areas supporting large volumes of defective timber. Such cutting is often necessary to abate high fire hazard effectively. It is wasteful where considerable volumes of sound but unmerchantable timber are present.	Expensive and wasteful on areas supporting large volumes of defective or unmerchantable timber, as much work is necessary to remove all but desirable seed trees. Reservation of suitable seed trees, usually highly merchantable, represents an appreciable investment in stumpage.	Involves reservation of merchantable trees for a second cut. Disposal of unmerchantable and defective timber by piling and burning necessary at either first or second cut. Most sound but unmerchantable timber is left for second cut or later, in hope that it may then be merchantable.	Continued forest production probably possible, but application greatly limited by difficulty of maintaining stands of desirable composition and growth rate.

One general defect of this early clear-cutting with seed blocks or strips was failure to provide for regeneration of the blocks or strips left uncut. Another was difficulty in controlling the extremely hot fires resulting from broadcast burning of the slash. Largely because of the latter, the method was virtually abandoned in 1913. In recent years, however, clear-cutting has attracted new interest because of the excellent reproduction resulting from most of this early cutting, increased experience, skill, and confidence in controlled burning (*10*), and greater recognition of certain distinct advantages of the method, and since 1929 it has again been practiced though not on a large scale.

Clear-cutting on the national forests of the western white pine region since 1929 has been princiaplly for the purpose of reducing the fire hazard on areas where timber has been killed by fire. Standing fire-killed timber frequently constitutes a fire hazard jeopardizing whatever reproduction becomes established beneath it as well as the timber on surrounding areas. In some instances, also, *Ribes* plants have come in after fire so abundantly that their eradication, necessary for control of the white pine blister rust, is practically impossible. In Forest Service Region 1 [38] clear-cutting and broadcast burning were carried out as a hazard-reduction measure in the 9 years 1929–37 on 14,300 acres, practically all in the western white pine type.

After clear cutting of fire-killed timber, followed by broadcast burning, planting is almost invariably necessary. The second burning of the area, to dispose of fire-killed trees that cannot be salvaged, is usually much more severe than the first. Most of this timber and all the organic mantle of the soil is consumed; nothing remains but a few heavily charred logs, ashes, and mineral soil. Herbaceous vegetation is often slow to appear on the twice-burned areas. In contrast, clear cutting of green timber and broadcast burning within 1 or 2 years remove less of the woody material and often leave the duff and humus merely scorched, with the result that herbaceous vegetation comes in promptly.

At present, clear-cutting of green timber on the national forests is largely confined to defective and overmature stands. A good example is furnished by several thousand acres of timber on the North Fork of the Coeur d'Alene River, Coeur d'Alene National Forest, sold to the Ohio Match Co. Most of this was cut under a rough shelterwood system, but on some areas with much defective grand fir and hemlock the pine was clear cut and the remaining stand, entirely unmerchantable, was felled and broadcast burned. On areas of a few acres each that were advantageously situated for reseeding from surrounding timber, reliance was placed on natural regeneration; larger areas were planted.

On the Deception Creek Experimental Forest, in the same drainage, a mature stand principally of western white pine was clear-cut in 1935 in strips 350 to 400 feet wide separated by uncut strips almost as wide and located as advantageously as possible for dissemination of seed (pl. 12, *A*). The cut-over strips were broadcast burned. On the strips not clear-cut, about 60 percent of the merchantable timber was removed, and with it sufficient unmerchantable timber to leave a rather open shelterwood. It is expected that the shelterwood will adequately reseed both the shelterwood and the clear-cut strips.

[38] Montana, notheastern Washington, northern Idaho, and northwestern South Dakota.

When sufficient reproduction has become established, the shelterwood will be removed. Advantages of combining methods in this instance are: (1) The entire stand will be reproduced at one time; (2) almost the maximum volume of merchantable timber is taken at the first cut—very little more timber is reserved than in a seed-tree cutting; (3) this merchantable timber is concentrated on less than half the total area, which tends to reduce logging costs. Slash was left in greatest volume on the clear-cut strips and was disposed of with a minimum of handling, by broadcast burning.

Specific advantages of clear-cutting as applied in stands including a high proportion of western white pine, on the less exposed sites, may be briefly summed up as follows:

1. It favors western white pine. After clear-cutting, on the more protected sites, white pine reproduces readily and at least holds its own with hemlock and grand fir, its principal competitors. It approximates Nature's usual way of regenerating the species, by lightning fires; most of the best white pine stands originated after fires that nearly, if not completely, destroyed the parent stand.

2. It is the only practicable method of restoring to productivity areas supporting large volumes of defective timber. The cost of removing such timber stands by any other method is prohibitive.

3. Minimum time is required for removing the parent stand and for starting a new one.

4. The surface soil is left in a condition favorable for initial seedling establishment of all species. (Further investigation is needed, however, to determine the full effect of burning on the soil and on seedling development.)

This method finds its best application in even-aged stands of merchantable timber fully ripe for cutting or in overmature stands containing large volumes of defective and unmerchantable timber. Every part of clear-cut areas should be within 200 to 400 feet of a seed source.

The method has these disadvantages:

1. It is wasteful where considerable volumes of sound but unmerchantable timber are present, since everything not logged is destroyed.

2. There is always the risk that the hot fires almost invariably necessary in broadcast burning may become unmanageable and do damage.

3. Clear-cutting that creates very large openings is not good practice on severe sites, where seedling establishment, particularly of western redcedar, is difficult.

A number of modifications of the clear-cutting method are possible, and often it can be advantageously combined with seed-tree or shelterwood cutting. Although its potentialities have not been fully investigated, it is believed that clear-cutting has a definite and permanent place in the management of the western white pine type.

Seed-Tree Cutting

By the seed-tree method, the area is clear-cut except for the minimum number of trees adequate to produce seed for natural regeneration. Seed trees of desirable species are selected principally for their ability to produce seed and for wind-firmness.

Marking rules adopted by the Forest Service in 1916 for all mature western white pine stands specified the reservation, per acre, of 14-inch or larger seed trees as follows: Two to six western white pines, either scattered or in groups; two to six western larches, or, if larch was not present, Douglas-firs; and a few western redcedars, if present. The rules specified also that all thrifty western white pine trees less than 14 inches in d. b. h. were to be reserved. At that time seed trees were considered as supplementing the seed stored in the duff, which was believed to be sufficient for natural regeneration in most instances. The fire-resistant larch was reserved to insure reseeding in case of fire. The rules provided also for the destruction, by fire or girdling, of defective or otherwise unmerchantable trees whose presence would impede natural regeneration of western white pine.

Subsequent to 1916 it was definitely determined, as has been stated, that seed stored in the duff could not be relied upon for natural regeneration. After that year, also, increased recognition was given to the fact that western white pine was reasonably wind-firm even when standing singly. (Losses have averaged only 5 to 10 percent over a 10- to 20-year period.) Accordingly, increased reliance was placed upon scattered seed trees. As more was learned of the characteristics of good seed producers, the rules were revised to specify in more detail what kind of seed trees should be left. In 1939, for mature but not decadent stands, they still specified the reservation of 2 to 6 well-spaced western white pine seed trees per acre, but further specify that these trees shall be 16 inches d. b. h. or larger, dominant or codominant, of good vigor, and with well-formed, healthy crowns, and that other species shall be cut as closely as market conditions permit.

Although these rules have been extensively applied, by no means all cuttings made since their adoption have been seed-tree cuttings as silviculturally defined. In practice, widely varying numbers of trees of species other than the selected white pine and other seed trees have often been left, for both silvicultural and financial reasons. The term "seed-tree cutting" has been loosely applied to most cuttings in which a definite reservation of merchantable white pine trees has been made, with little regard for other components of the residual stand. These variations have resulted principally from the presence of large numbers of unmerchantable trees on most cutting areas and from recognition of the need for protection on the more severe sites during the regeneration period. Many so-called seed-tree cuttings are in reality shelterwood or no more than rough diameter-selection cuttings. The discussion here is limited to such cuttings as can actually be considered seed-tree cuttings in accordance with the accepted silvicultural concept.

The quantity and species composition of established natural regeneration on four seed-tree areas studied 9 to 14 years after cutting are shown in table 44. On the Phil McManimin and Rose Lake Lumber Co. areas the primary seed source was scattered uncut groups located on secondary ridges, knolls, and slopes, but these were supplemented by scattered single trees. On the two other areas, principal dependence was placed on scattered seed trees, although some small seed-tree groups were left. On all four areas, all defective or otherwise unmerchantable grand fir and western hemlock trees were destroyed by girdling to remove overhead shade that might retard

seedling establishment and growth. The reproduction figures given in table 44 do not by any means furnish a criterion of the efficacy and worth of the seed-tree method; but they do give, with the possible exception of those for the Rose Lake Cathcart area where much of the cutting was on an exposed site, a general indication of what is considered satisfactory regeneration. Site conditions influencing natural reproduction are much the same on seed-tree cuttings as on clear cuttings, and in general the quantity, species composition, and development of the natural reproduction are similar.

Specific advantages of the method, for application in mature stands where most of the timber is merchantable, may be summed as follows:

1. Like the clear-cutting method, it is especially suitable for regeneration of western white pine on the less exposed sites.
2. If properly applied, it can be depended upon to effect establishment of a new stand of desirable composition.
3. Eventual removal of the seed trees, although desirable utilization, is not silviculturally necessary.

TABLE 44.—*Natural regeneration on four areas after cutting by scattered-seed-tree and seed-group method, in established seedlings per acre*

Name and locality of area	Period since cutting	Western white pine	Other species	All species
	Years	*Number*	*Number*	*Number*
Phil McManimin, Lindberg Creek	14	2,525	8,528	11,053
Rose Lake Lumber Co.:				
Lindberg Creek	11	1,245	5,630	6,875
Cathcart Creek	9	817	3,889	4,706
McGoldrick Lumber Co., Sands-McCauley Creek	9	1,310	7,199	8,509

4. The volume of merchantable timber removed at the first cut is the maximum that will leave enough trees to insure natural regeneration. Because logging costs are high in the western white pine type, especially for the first cut, this is a major reason why the method has been applied.

Best application of the method is in even-aged stands consisting principally of mature western white pine.

Seed-tree cutting has these disadvantages and limitations:

1. It is expensive and wasteful in stands containing large volumes of unmerchantable timber, which must be cut to make the seed trees effective. In such stands, if the unmerchantable timber has no potential value, clear cutting is usually preferable. Otherwise, some sort of shelterwood or selective cutting may be advisable, to reserve the timber now unmerchantable for a future cut.
2. It cannot be applied on areas where because of defectiveness or age of timber, shallowness of soil, or exposure to severe winds it is impossible to select desirable seed trees that have a reasonably good chance of surviving long enough to produce sufficient seed for regeneration.
3. It does not give good results on the more severe sites such as south slopes and exposed flats, where some shade is necessary for satisfactory regeneration, particularly of western redcedar.
4. Seed trees represent an appreciable stumpage value, yet their aggregate value is often insufficient for a profitable second cut and not many of them are likely to survive a full rotation.

Shelterwood Cutting

By the shelterwood method, the mature stand is removed in two or more partial cuttings. Natural reproduction starts under the shelter of a considerable part of the parent stand, and when established is released by complete removal of the last of the parent trees. To quote Hawley (*21*):

> A minimum of two cuttings are required in the simplest application of the shelterwood method. Under intensive management several cuttings, often exceeding ten in number, are made in the gradual process of simultaneously freeing the reproduction and removing the mature stand.

Probably the majority of cuttings in the western white pine type have left residual stands of the shelterwood type, though relatively few have been definitely intended as shelterwood cuttings. As previously mentioned, many so-called seed-tree cuttings on the national forests were actually shelterwood cuttings, as they left large numbers of unmerchantable trees standing in addition to selected seed trees. Many of the cuttings made on private lands also left shelterwoods, often of an undesirable sort. In few instances, however, has sufficient time elapsed since the first cut for reproduction to reach a stage of development necessitating a removal cut, and in still fewer instances has this cut been made. Experience with the shelterwood method in the type is therefore limited to a rather wide variety of partial cuttings that together with secondary cuts made in due course of time would constitute a rough shelterwood method.

Under favorable circumstances, excellent reproduction may be expected to result from a shelterwood cutting. This is well illustrated by the Ryric-Wright sale area on the Coeur d'Alene National Forest, one of the few intentional shelterwood cuttings made in the type. Here the original cutting, in 1910, left a shelterwood containing, per acre, an average of 28 white pines 14 inches or more in diameter, 16 other trees of that size, and about 200 smaller trees. In 1925 the established reproduction stand on this area included, per acre, 3,767 white pines and 5,355 seedlings of other species. This reproduction stand was satisfactorily distributed over the area, all aspects and situations being adequately stocked.

A variation of the shelterwood method that has been tested experimentally is disposal of defective and other low-value trees by a stand-improvement operation in advance of commercial cutting. This procedure creates shelterwood conditions favorable to the establishment of reproduction of desirable species. When the reproduction has become established the shelterwood, composed principally of merchantable trees, is removed and the reproduction is left to grow under clear-cut conditions, which promote best white pine development.

Particular mention should be made of what is popularly termed zero-margin selective cutting and its relation to regeneration methods, particularly the shelterwood. By zero-margin cutting is meant cutting only trees of such size and condition as will produce the greatest net-per-acre return to the operator. The term is rather loosely applied to most cuttings in which tree selection is based principally on immediate conversion value and not upon silvicultural considerations. Cuttings of this type have been made most extensively on privately owned timberlands where economic pressure for profitable conversion is in-

tense. Every logging and milling study has shown that sound trees below a certain diameter and larger trees with a specified quantity of rot or other defect are logged at a loss and from a financial standpoint might better be left standing. Depending on the composition and condition of the timber stand, the financial organization of the operator, and current market conditions, cutting under a zero-margin plan may vary from virtual clear cutting to a light selective cut. Cuttings of this type may, therefore, fall into any of the commonly recognized regeneration methods; most of them, however, can be classed as the crude beginning of a shelterwood method.

Silvicultural results of zero-margin cutting in the western white pine type are variable. If the cutting leaves a considerable number of trees of desirable species, and at the same time opens up the stand sufficiently to permit the establishment of reproduction, the results are fairly satisfactory. This is particularly true in young, thrifty stands. Here, sufficient basis for a second cut remains, and good reproduction usually results. If a second cut can be made to release reproduction from the residual overwood, and if unsatisfactory composition of the reproduction can be corrected by cleaning, good second-growth stands can be produced.

In mature stands containing large volumes of defective and unmerchantable timber, the silvicultural results of zero-margin selection applied without restraint are usually anything but satisfactory. The first cut removes the merchantable part of the stand, leaves defective and low-value trees dominating, and thus makes a profitable second cut very difficult. Experience has shown also that in mature and overmature stands the residual stand often deteriorates rapidly, being subject to insect damage, wind breakage, and the like. Private land thus logged is sometimes virtually broadcast burned in an attempt at cheap slash disposal. The result is often a maze of fire-killed timber that in a few years constitutes an especially high fire hazard.

Initial establishment of adequate numbers of seedlings under a shelterwood is seldom a problem. Seed of all important species in the type will germinate, and seedlings of white pine and most of the other species will survive for a few years, under a fairly dense residual stand. But getting reproduction stands of desirable species composition, insuring their satisfactory subsequent development, and disposing of the residual stand at the proper time constitute a problem. This problem is especially difficult in connection with zero-margin selection, because the shelterwood left by such cutting is composed largely of undesirable trees and so tends to generate a reproduction stand of undesirable species composition, for example one dominated by western hemlock and grand fir. Timely release of the reproduction is difficult because of the unmerchantable character of the residual parent stand. The marked effect of overwood density on the species composition and growth of reproduction beneath is well illustrated by plates 5 and 6.

In summary, advantages of the shelterwood method in the western white pine type are:

1. It effects successful reproduction of all species common in the type, with the possible exception of western larch and lodgepole pine.
2. It is more effective than any other method on the more exposed sites, where reproduction cannot become established without shelter.
3. A forest cover is maintained continuously.

4. In stands containing much sound but currently merchantable timber, this method permits harvesting most of the merchantable timber and reserving the residual stand for a decade or two, within which it may become merchantable.

Scored against the shelterwood method are these disadvantages:

1. Before it can be applied effectively, better markets for timber of mixed species must develop than have prevailed in the past.

2. Economic considerations oppose the reservation of any volume of merchantable timber greater than the bare minimum left by the seed-tree method, particularly as regards privately owned timberlands.

3. Species composition and development of reproduction are usually less satisfactory than under the clear-cutting or the seed-tree method. Hemlock and grand fir tend to occupy more prominent positions at the expense of the more valuable white pine. Cultural measures are often necessary to correct unsatisfactory composition.

Capable of many modifications and adaptations to reconcile frequently conflicting economic and silvical considerations, the shelterwood method is believed to be more generally desirable than any other applicable in the western white pine type.

Selection Cutting

The selection method presupposes that all age classes are proportionally represented and intermixed either on every acre or over the cutting unit as a whole. Each year or at some longer specified interval mature trees, either in small groups or singly, are removed, with the result that an all-aged forest is maintained continuously. Under intensive management, cuttings are frequent and light; under management such as prevails in the United States, fewer and heavier cuttings are made, each part of the cutting area being visited at intervals of 10 to 50 years.

This method cannot be said to have been actually applied in the western white pine type. Some cuttings have been made that could be considered the initial steps in selection management, but insufficient time has elapsed since the inception of cutting in the type for the method to have been tested in practice. Natural stands in the type tend strongly to be even-aged, or made up of not more than two or three age classes. Some approach an all-age condition, but most of these are very old and of low value.

Judging from what is known of western white pine silviculture, the selection method offers distinctly limited possibilities in this type. Reproduction could be established by it, but neither the species composition nor the subsequent growth of the reproduction stand would be satisfactory. Natural selection in the type favors the more tolerant species, which, with the exception of western redcedar, are the least valuable. There is little reason to suppose that man-directed selection would have any different result, especially since for economic reasons the most valuable species would almost inevitably be cut first, leaving the less desirable to reproduce themselves. In other words, a forest could be maintained by the selection method, but it would not contain much western white pine, Douglas-fir, or western larch.

SUMMARY

The western white pine type of northern Idaho and contiguous portions of Washington, Montana, and British Columbia is composed principally of western white pine, western larch, Douglas-fir, grand fir, western redcedar, and western hemlock, with Engelmann spruce, alpine fir, lodgepole pine, and ponderosa pine as minor components. These species differ considerably in their requirements, and this fact, together with the mountainous character of the region, gives the type great silvical diversity. The type is defined as mature stands containing 15 percent or more western white pine by volume and young stands containing 15 percent or more western white pine by number of trees. The composition of the stands varies from almost pure pine to every conceivable combination of pine with its associates.

Western white pine composes nearly half the merchantable volume of the type and excels all the other species in value. The lumbering industry of the Inland Empire is largely built around white pine. Second in importance is western redcedar, valuable chiefly for poles. The relatively low market values of Engelmann spruce, Douglas-fir, western larch, and grand fir, make extensive logging of these species unprofitable. Western hemlock often has practically no stumpage value. Hemlock and grand fir tend to be so defective in mature and overmature stands as to constitute a definite liability. Disposal of large volumes of low-value or totally unmerchantable timber, often essential in the application of desirable silvicultural measures, is a major management problem of the type. Economic and silvicultural aims are often in direct conflict, and the former frequently dominate.

The climate of the western white pine region is characterized by a short summer season of scanty precipitation and low humidities, with a high proportion of clear, hot, sunny days, and long winters with heavy snowfall and fairly low temperatures. Mean annual precipitation ranges from 28 to nearly 50 inches. Annual snowfall averages 103 inches, ranging from 48 inches at the southern border to 244 inches at the upper altitudinal limit. At most of these stations, snow lasts until about the end of April and first snow appears toward the end of October. Only about 15 percent of the total precipitation occurs during the summer months, June, July, and August. Annual mean temperatures range from 41.7° to 50° F. Daily temperature fluctuations average from 34° to 42° in July and August and from 12° to 19° in January. Yearly maximum temperatures average about 100°, and yearly minima average well below zero. Sudden drops in temperature occasionally cause widespread injury even to mature trees. The growing season is approximately the 4 months May through August. During this period scanty precipitation, high temperatures, and low humidities accompanied by high evaporation rates often combine to produce critical conditions for the establishment of natural regeneration. Evidence has been found that extension of the western white pine type is limited at high elevations by unfavorable temperatures, and at low elevations by a combination of low moisture with high temperatures. Growth of western white pine is favored apparently by climatic conditions for which the precipitation-effectiveness indices, calculated according to Thornthwaite's method, are about 110 for the year and 11.5 for the growing season.

Fire, fungi, and insects are the principal causes of injury in the western whie pine type. Fire causes heavy direct losses and also contributes greatly to the incidence and spread of fungi and insects. The fire-control problem is one of the most difficult in the country. Fire colors every phase of management practice; methods of cutting, stand improvement, and slash disposal must frequently be modified to conform with fire-control requirements. Fire, however, is largely responsible for the perpetuation of the western white pine type under natural conditions. Disease also is responsible for some of the most difficult management problems. The problem of low-value species is intensified by their susceptibility to wood-rotting fungi. The white pine blister rust threatens the very existence of western white pine as an important component of the type. Large sums have been and must yet be spent to control this disease. Forest insects exact an annual toll that varies from an unimportant loss to devastation, leaving the stand not worth logging.

Western white pine trees produce comparatively few cones; a crop of 40 cones per tree is considered good, and crops of more than 100 cones per tree are infrequent. Number of seeds per cone varies with size of cone and extent of insect depredations; 120 seeds per cone is a fair average. Seedbed germination averages 44 percent. An individual tree has been known to bear 7,300 germinable seeds.

Western white pine trees bear good crops at intervals averaging about 3 to 4 years and varying widely among individual stands. Five good cone crops have been known to be produced in 9 years in one stand; in another, not one good crop was produced in 7 years.

Most western white pine seed is borne by vigorous dominant or codominant trees. Good-vigor trees become effective seed producers at diameters of about 14 inches and may bear seven times as many cones as poor-vigor trees, which are ineffective seed producers at any diameter. Fair-vigor trees consistently produce fewer and poorer cone crops than do good-vigor trees of the same diameter, and are not effective seed producers at diameters of less than about 20 inches. Trees become fairly frequent and abundant seed producers at about 70 years; thereafter, seed production depends more on individual tree vigor and character of crown than on age. Of the principal western white pine associates, western hemlock and western redcedar are outstandingly abundant seed producers.

Seed dissemination of most species in the type begins in late August or early September. About 15 percent of the western white pine seed reaches the ground before September 1, and 85 percent by the end of October. Of the seed of grand fir, western larch, and Douglas-fir, from 65 to 80 percent falls by the end of October. Seed of western hemlock and western redcedar falls most abundantly in October, but 35 to 45 percent of it falls after November 1. Western white pine seed is commonly distributed in quantities sufficient to produce adequate reproduction not farther than about 400 feet from the parent tree.

Seed of all species in the type is stored naturally in the duff in the fall and remains viable until the following spring. Seed of western white pine alone remains viable in appreciable quantity longer than the normal overwinter period. About 25 percent of it is viable the second year after storage, and slightly less than 1 percent after 3 years' storage.

Seed stored in the duff and seed produced at the time of logging or fire are sometimes adequate but cannot be relied upon for natural regeneration; not more than one out of four cut-over areas is satisfactorily regenerated without a continuing seed source, either scattered seed trees or adjacent uncut timber.

Germination begins in late April or early May on exposed sites, where snow lingers late. It is practically completed by July 1 on exposed sites and by August 15 on protected sites. Germination is markedly affected by the character of the surface-soil material. Mineral surfaces, burnt or unburnt, are better than duff surfaces, probably because duff surfaces dry out rapidly. On seed-tree cuttings, the larger-seeded species—western white pine, Douglas-fir, grand fir—germinate nearly as well on duff as on any other surface, but western hemlock and western redcedar germinate only one-tenth to one-fifth as abundantly on duff surfaces. Germination on rotten wood tends to be better than that on duff; this advantage, however, is counterbalanced by higher seedling mortality due to drought.

Nearly 50 percent of all seedlings die in the first season. Losses drop off rapidly after the first year, and seedlings 2 years old are fairly well established. Studies of mortality during the critical first year indicate that early-season losses are due principally to biotic agents. Of these, damping-off fungi are the most important. Fungi-caused losses are irregular, however, and consistent differences between species or habitats as to such losses have not been established. Insects, rodents, and birds sometimes cause serious seedling losses.

As the season advances and the soil begins to dry, biotic losses largely cease, and mortality thereafter is due principally to physical agents. Insolation, causing high surface-soil temperatures, is the most important agent of mortality on exposed sites. Injurious surface-soil temperatures, beginning at about 120° F., occur commonly during the summer months on the more exposed sites. Temperatures are highest on duff, making this surface especially hazardous on exposed sites. They are somewhat higher on burnt mineral than on natural mineral surfaces, owing to greater absorption of heat by the blackened surface. Surface-soil temperatures are less important under shade or on sheltered sites, and under fairly dense shade or on north slopes are not a cause of mortality. Western white pine, grand fir, and Douglas-fir are the species most resistant to heat injury, western larch is intermediate, and western hemlock and western redcedar are relatively susceptible.

Seedling mortality from drought, the second greatest physical factor, is directly governed by the relation between soil moisture and root penetration. If seedlings can extend their root systems in pace with receding soil moisture as the season advances, drought mortality will not be important. On areas exposed to full sun the deep initial root penetration of western white pine, Douglas-fir, western larch, and grand fir protects these species from drought losses despite early drying of the surface soil, but the shorter-rooted western hemlock and western redcedar suffer heavily. On heavily shaded, cool, and relatively moist areas, drought is paradoxically the most important physical cause of mortality. Here initial root penetration of all species is slower, and even shallow drying of the surface soil may cause drought mortality despite ample soil moisture at deeper levels.

All factors considered, seedling establishment of all the principal species of the type on severe to moderately severe sites is best under part shade. On more sheltered sites such as north slopes, light shade or clear-cut conditions are best. As regards initial mortality, western white pine, western larch, Douglas-fir, and grand fir are resistant species, western hemlock and western redcedar relatively susceptible.

The problems of natural regeneration do not end with successful seedling establishment. Seedlings stands may originate under conditions inimical to satisfactory subsequent growth, and to only a distinctly limited extent can composition of the seedling stand be controlled. After establishment, requirements of individual species for best growth differ widely. On exposed sites lodgepole pine and western larch develop best on areas almost without shade, where they make the most rapid growth of any species in the type. On such sites western white pine, Douglas-fir, and grand fir, though also hardy, are benefited by moderate overhead shade during the early years of stand development. On protected sites, however, these species make best growth under clear-cut conditions. Western hemlock and western redcedar require shade for best development even on relatively protected sites, and can exist for long periods under dense shade. These species, and also grand fir, make better development than western white pine and other associates under moderately dense shade. During the period of early development, roughly the first 30 years, rate of growth and species composition can be effectively controlled by cleaning and by regulation of overwood density.

Regeneration methods applicable in the western white pine type include clear-cutting, seed-tree cutting, shelterwood cutting, and selection cutting.

Clear-cutting, either in strips up to 400 feet wide or in fairly large groups, is well suited for reproduction of stands on the less exposed sites that include a high proportion of western white pine. It is not a good method on severe sites if it creates very large openings. Best application is in even-aged stands of merchantable timber fully ripe for cutting or in overmature stands containing large volumes of defective and unmerchantable timber. It is a wasteful method where considerable volumes of sound but unmerchantable timber are present that may become merchantable in the future. Clear-cutting can often be combined advantageously with seed-tree or shelterwood methods.

The seed-tree method, that is, clear-cutting with the reservation of selected seed trees, is widely used on the national forests in the western white pine region. It is well suited to regeneration of western white pine stands on more sheltered sites. If properly applied, it is dependable. It removes at a single cut the maximum volume of merchantable timber over extensive areas that will leave enough trees to insure natural regeneration. Application is best in even-aged stands consisting principally of mature western white pine, and the most expensive and wasteful in stands containing large volumes of unmerchantable timber. Forest Service timber-marking rules specify reservation of two to six well-spaced western white pine seed trees, with a few trees of other species. Western white pine trees selected for seeding purposes should be dominants not less than 16 inches d. b. h., of good vigor, with well-formed, normal crowns. Western white pine is relatively wind-firm; losses have averaged only 5 to 10 percent over a

10- to 20-year period. A second cut to remove seed trees is not essential silviculturally.

Probably most cuttings in the western white pine type have left residual stands of the shelterwood type, though relatively few have been so intended. "Zero-margin" selection cutting usually leaves such stands. The shelterwood method consists in removing the parent stand by two or more cuts, natural reproduction becoming established under the shelter of a considerable part of the parent stand. In few instances has reproduction following the first cut yet become sufficiently advanced to necessitate a second cut, and in still fewer instances has the second cut been made. All the principal associates in the type reproduce readily under shelterwood, with the possible exception of western larch and lodgepole pine. The proportion of western white pine is usually not so high as under the seed-tree or the clear-cutting method, necessitating cultural measures to correct unsatisfactory composition. The method is especially suitable in stands containing much sound timber of desirable species but of less than merchantable size, which can advantageously be left for a second cut. It does not give good results where the stand left after the first cut consists principally of trees not worth logging. Composition of the reproduction stand is then usually poor, and the difficult problem of disposing of unmerchantable trees is passed to the future.

Selection cutting, the method of repeated cuttings by which an all-aged forest is maintained continuously (not to be confused with zero-margin selection cutting), cannot be said to have been actually applied in the western white pine type, although some cuttings made in the type have resembled it. It appears to offer relatively limited possibilities in this type, as it tends to favor the more tolerant species, which, with the exception of western redcedar, are the least valuable.

According to present knowledge, the clear-cutting, seed-tree, and shelterwood methods all deserve a place in the management of the western white pine type. Forest conditions are too diverse and the necessity for compromise between silvicultural and economic aims too pressing for any one method to suffice. Selection of the particular method to use on a given area should be based on careful, rational appraisal of economic and silvicultural factors.

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