A STUDY of PONDEROSA PINE PRODUCTION in CENTRAL IDAHO

by James D. Curtis

INTERMOUNTAIN FOREST & RANGE EXPERIMENT STATION

FOREST SERVICE,
U. S. DEPARTMENT OF AGRICULTURE.
OGDEN, UTAH.

Reed W. Bailey, Director.

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ECONOMIC SIGNIFICANCE OF THE SPECIES

Ponderosa pine (*Pinus ponderosa* Laws.) ranks next only to Douglas-fir (*Pseudotsuga menziesii* /Mirb./ Franco) and the southern pines in volume of timber cut annually in the United States. It is harvested in thirteen western states and the province of British Columbia and thus claims the attention of forest managers over a considerable area.

The ponderosa pine type is commonly the lowest altitudinally of western commercial forests of the mountain country and consequently serves, directly and indirectly, as a major source of economic usefulness. Water and its quality, the pulse of existence and farming in the arid valleys are influenced by the pine type; millions of people picnic, hike, fish, and hunt over the vast areas supporting it. The wood has desirable and valuable properties and hence finds specialized and varied uses in all parts of the continent.

PROBLEMS OF MANAGEMENT

Management problems of the ponderosa pine type are distinct and complex but do not defy solution. Growing where precipitation is usually close to 23 inches annually and where summer rainfall is commonly below an inch, found on basaltic, sandstone, limestone, or desiccative granitic soils often in rugged terrain where logging is formidable and costly, where fire risk from lightning storms and the human element is high, ponderosa pine management challenges the resourcefulness of both the researcher and the manager.

Of the many aspects of management perhaps the most important is the difficulty of securing high growth per acre. How to cut ponderosa pine forests and secure a net growth of 150 feet board measure per acre per year in the residual stand requires skill and prescience possessed by few silviculturists. The brief annual growth period, the scant rainfall, the low water-holding capacity of the soil, the relatively few frost-free days, and the timber-killing insects, all combine to aggravate conditions already difficult for acceptable net growth although growth *per se* is reasonable enough. Mortality of sawtimber is mostly due to insects of which the western pine beetle (*Dendroctonus brevicomis* Lec.) is by far the most important although the mountain pine beetle (*Dendroctonus monticolae* Hopk.), the pine butterfly (*Neophasia menapia* Feld.), and *Ips* are among the more important latent threats. Neither is there assurance that the difficulty of reducing mortality will diminish as the older age classes are removed because entomologists believe the emphasis may shift to other insects in the younger age classes in the discernible future.

While disease can be a factor of measurable proportions in reducing net growth, it is fortunately not as widespread nor as severe as the loss from insects. It is nevertheless becoming increasingly important, and means and technics for recognizing incidence and coping with outbreaks are now accepted more realistically than heretofore.

Of all phases of ponderosa pine management the establishment of reproduction is the most troublesome and certainly the most frustrating. The absence of seed crop periodicity, the seed-eating rodents and birds, the low precipitation--a vital factor in the first few years of growth--the high soil surface temperatures generated in summer, and the competing vegetation, all combine to militate against the natural or artificial replacement of growing stock on cutover areas. The coincidence of abundant seed and ample precipitation the following spring and summer, which is necessary for successful stocking, is infrequent and unpredictable. The Black Hills alone invariably enjoys this fortuitous combination. This obstacle of securing reproduction aggravates the difficulty of planning and applying regulation, the keystone to successful sustained yield management of all forest crops. Reproduction already present in pine forests all too often gives the impression that it is easy to secure. Nothing could be further from the truth. Unless sense and caution are exercised, crop establishment can represent an impressive investment per acre. It should be evident to all that every means at the forest manager's disposal should be directed towards reducing damage to advance reproduction during logging, a field where greater effort is needed.

While many extensive areas supporting ponderosa pine are of gentle topography many others including central Idaho, western Montana, and some parts of Oregon are not. This means increased logging expense, more damage to precious advance reproduction, and costlier postlogging measures where soil is erosible as in central Idaho.

Unlike many forest types, no market exists for ponderosa pine thinnings which is an obvious disadvantage in the management of immature stands. The Coconino Plateau in Arizona is a conspicuous exception. While this difficulty may be overcome within a reasonable time, spurred by the rapid development of utilization standards and regional economic trends, present means of profitable timber stand improvement practice are limited in scope. This is unfortunate because all ponderosa pine forests are deficient in intermediate-size classes. Thus there is lost a direct means of profitably increasing the growth rate of the smaller sized stems to sustain a continuous flow of merchantable material in later cuts. The lack of thinning practice also has an adverse effect on the results of artificial pruning, a necessary practice if high-quality lumber is to be produced on short rotations, because in unthinned stands diameter growth is only moderate which results in slower healing of branch cuts. The cost of this pruning is an outright gamble on future market demand and assumes that the current price differential between high and low lumber grades will persist indefinitely. While this may be a logical and reasonably safe prediction, artificial pruning is nevertheless one more cost of management.

THE EXPERIMENT

The many problems of ponderosa pine management related above are common to the type throughout the Intermountain country. The study described here was formulated and initiated as a result of a problem analysis made for forest management research in the Intermountain Region[1/] in which all problems were listed and considered in order of priority. Because the need for better silvicultural management of ponderosa pine transcended all others, it was decided to initiate an experiment which would help to answer the most urgent problems. The main objectives of the experiment are therefore:

A. To discover how to cut and log mature ponderosa pine to insure the highest possible net growth per acre, minimum damage to site and advance growth, and the successful establishment of reproduction.

B. In conjunction with trials of cutting to secure detailed growth data which would permit reliable predictions of net sawtimber growth.

C. To develop economically and silvically sound treatments to improve composition, growth, and quality of sapling and pole stands.

In designing the experiment, it was important to keep the number of variables to a minimum, and to employ them in a way which would permit biometric analysis. The variables to be tested were carefully chosen and were considered to be basic and decisive in their influence on the establishment and growth of seedlings and the development of young stands to maturity. Thus the danger of the study becoming outmoded was permanently minimized. The two reproduction (marking) methods, for example, represent classic and commonly misunderstood silvicultural systems-stem (individual tree) selection and group selection. These two systems produce strikingly different environmental conditions affecting

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1/ Curtis, James D. 1949. A problem analysis for forest management research in the Intermountain Region. Intermountain Forest and Range Experiment Station, U. S. Forest Service, Ogden, Utah. Unpub. ms. 45 pp.

establishment and growth of trees such as seed supply, light, seedbed, soil moisture availability, and later the evenaged and unevenaged character of individual stands.

Similarly, the two levels of reserve volume include variations in many stand characteristics which influence subsequent growth of residual trees as well as the regeneration of the next crop.

The two tractors chosen represented the practicable extremes in logging "cats" and indirectly produced measurable variations in soil disturbance, damage to advance growth, and erosion hazard. Lastly, the volume of the original stand reflects important differences in site quality with all the ramifications in tree vigor and surface vegetation which, in turn, affect regeneration and growth.

Accordingly, these four variables, (1) reproduction method, (2) level of reserve, (3) size of tractor, and (4) stand volume class were included in the design. Eight combinations are possible among the first three of these variables, and these combinations were established on eight compartments (minor drainages). The compartments were then split three ways according to the three levels of original stand volume. Finally, the eight compartments were replicated to make 16 in all. Figure 1 shows one replication of eight compartments starting with the original stands and the treatments imposed on them.

THE INSTALLATION

The first step in the installation was the identification and location of minor operable drainages on the Boise Basin Experimental Forest which would serve as "plots" or areas of comparison. These were called compartments. It was necessary that they approximate at least 30 to 50 acres in extent so that each contained the three volume classes decided on as readily identifiable. This was accomplished by use of aerial photographs and stereograms.2/ These three volume classes or treatment units, each of which contains a minimum of 10 acres in each compartment, were:

Volume Class I averaging - 0 - 10,000 f.b.m. per acre
Volume Class II averaging - 10 - 20,000 f.b.m. per acre
Volume Class III averaging - 20,000 or more f.b.m. per acre

2/ Wilson, Alvin K. 1954. Delineating ponderosa pine volume and site quality classes from aerial photographs. Research Paper 34, Intermountain Forest and Range Expt. Station, Forest Service, Ogden, Utah.

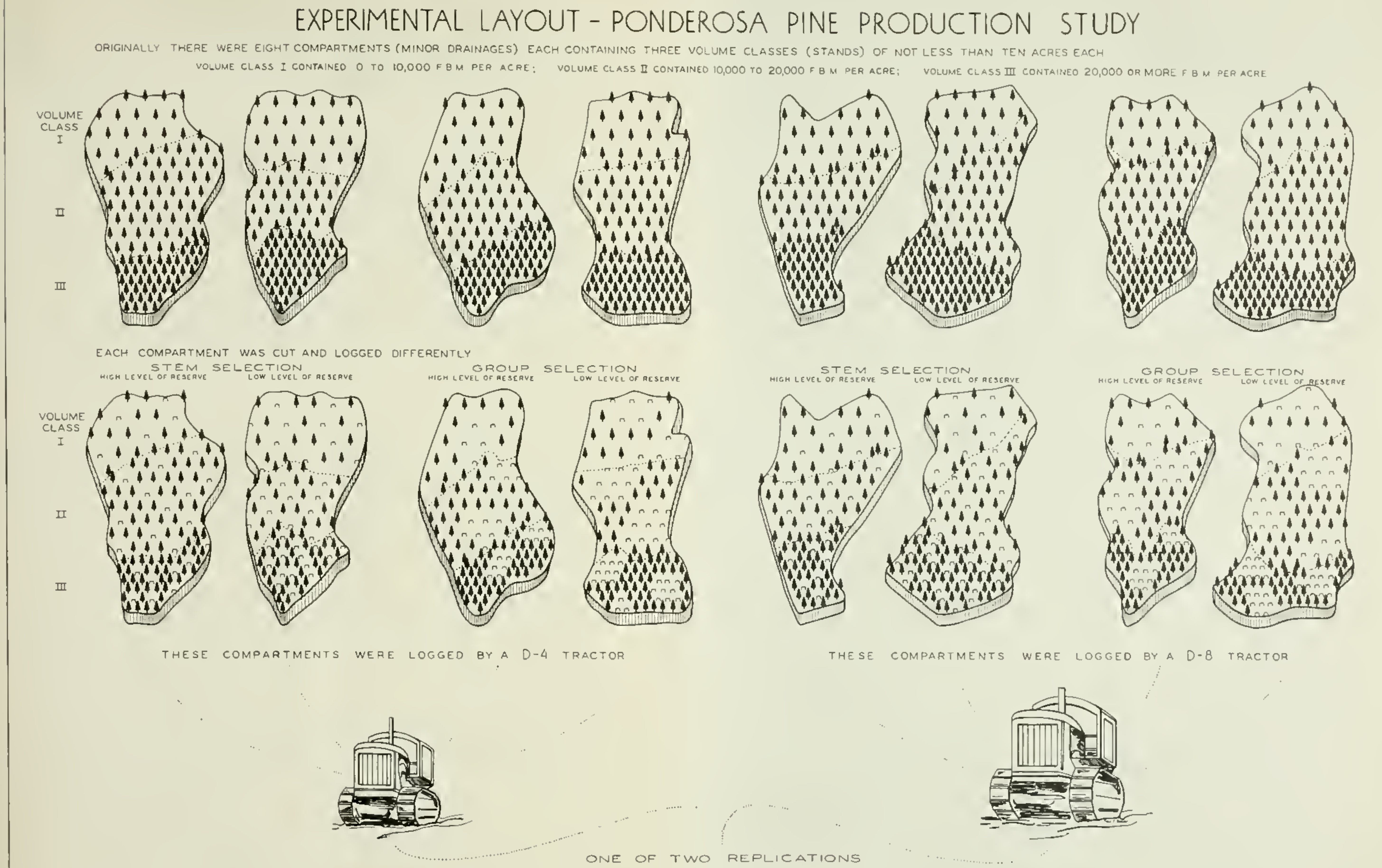
EXPERIMENTAL LAYOUT - PONDEROSA PINE PRODUCTION STUDY
ORIGINALLY THERE WERE EIGHT COMPARTMENTS (MINOR DRAINAGES) EACH CONTAINING THREE VOLUME CLASSES (STANDS) OF NOT LESS THAN TEN ACRES EACH
VOLUME CLASS I CONTAINED 0 TO 10,000 F B M PER ACRE; VOLUME CLASS II CONTAINED 10,000 TO 20,000 F B M PER ACRE; VOLUME CLASS III CONTAINED 20,000 OR MORE F B M PER ACRE
VOLUME CLASS
I
II
III
EACH COMPARTMENT WAS CUT AND LOGGED DIFFERENTLY
STEM SELECTION
HIGH LEVEL OF RESERVE
LOW LEVEL OF RESERVE
GROUP SELECTION
HIGH LEVEL OF RESERVE
LOW LEVEL OF RESERVE
STEM SELECTION
HIGH LEVEL OF RESERVE
LOW LEVEL OF RESERVE
GROUP SELECTION
HIGH LEVEL OF RESERVE
LOW LEVEL OF RESERVE
VOLUME CLASS
I
II
III
THESE COMPARTMENTS WERE LOGGED BY A D-4 TRACTOR
THESE COMPARTMENTS WERE LOGGED BY A D-8 TRACTOR
ONE OF TWO REPLICATIONS

FIGURE 1

There are two replicates of 8 compartments each, a total of 847 acres. Compartment boundaries are marked on trees in the field by yellow paint spots; volume class boundaries by blue paint spots. Each compartment was cruised by classes and all trees numbered with temporary cardboard tags. Number, species, diameter, risk and/or tree class[3/, 4/, 5/] were recorded for each tree 11.0 inches d.b.h. and over.

Reproduction Methods.--Two reproduction (marking) methods are being tested--Stem Selection and Group Selection. In the former, effort is directed towards removing those individuals which it is believed will not live until the end of the 15-year cutting cycle with the purpose of increasing net growth per acre by reducing volume mortality. Briefly, this method assumes that mortality is always latent, even in the younger age classes--a fact which previous research has shown to be true. It might be adduced that because ponderosa pine is an intolerant species it is not suitably manageable under stemwise selection. The fact is that loss from sawtimber mortality cannot be systematically minimized otherwise except by removal of all merchantable trees. This would be undesirable where the objective is to secure and to sustain a high net growth rate. Because the species is naturally disposed to occur groupwise, stand structure need not be greatly disturbed by this system of cutting but net growth can be substantially increased.

In Group Selection the overmature and mature trees are clear cut in groups, commonly from 0.25 to 0.75 acre in area. The size of the group is largely determined by the size of the stand to be cut although occasionally two small stands, slightly separated, can be "joined" thus making a more workable unit. The clear-cut groups are therefore the initial stage of small even-aged stands which are separated from other even-aged stands by virtue of this discontinuity of cutting and with obvious advantages of protection. It follows that the development and treatment of these separate stands are facilitated and are desirable silvically because of their even-agedness and homogeneity.

Because the initial stands of each volume class varied both in volume and risk, it was not possible to have reserve stands equal in risk though they were equal in volume for corresponding levels of reserve. With few exceptions, however, all (Salman-Bongberg) risk classes

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3/ Salman, K. A. and J. W. Bongberg. 1942. Logging high-risk trees to control insects in the pine stands of northeastern California. Jour. Forestry 40: 533-539.

4/ Keen, F. P. 1943. Ponderosa pine classes redefined. Jour. Forestry 41: 249-253.

5/ Wilson, Alvin K. 1952. An age-vigor tree classification for Douglas-fir in central Idaho. Jour. Forestry 50: 929-933.

III and IV were removed by cutting in the two methods of reproduction or marking. Rotation age for both methods is tentatively set at 180 years.

In the Stem Selection method, trees of highest mortality risk (S-B IV and III, Keen 4D, 3D, 3C) were marked first followed by those of next highest risk until the specified average per acre reserve volume for the particular volume class area was reached. Because all risk classes were available from cruise sheets and each tree numbered, it was a simple task to relocate the trees to be marked. In the Group Selection method, the area of each stand for a volume class was taken from the stand map of each compartment. On the basis of a 180-year rotation and cutting every 30 years to establish reproduction, there will be six age classes and the area occupied by any one of them will be one-sixth of the total area of the unit, in this case the area occupied by a volume class. Control of cutting, therefore, was achieved by first marking the groups of overmature trees with no understory until the predetermined area quota for the youngest (reproduction) age class was met. This is followed by selecting stands which occurred as overstory above seedlings or saplings, thus freeing to grow the next older age class, equal in area to the youngest age class. Likewise, the next step was to remove overstory over poles.

This scheme was continued as far as area allotments and the prescribed level of reserve would allow. In many cases, a stage was reached in marking where the remainder of the allowable cut was insufficient for further effective work toward the attainment of groupwise stand structure. This situation can be expected in initial cuttings of this kind, especially where there is a deficiency or excess of a particular age class. In such cases, individual high-risk trees between the groups were marked, until the desired level of reserve was met. In following this system a substantial number of high-risk trees were automatically removed and hence a two-fold purpose in management was achieved with attendant and obvious advantages. Cuts to "shape up" groups (to delineate them better) and decrease mortality risk will be made 15 years after each reproduction cut. It should be obvious that the degree of refinement used in installing the cutting systems in this experiment, would not be employed in their application.

Levels of Reserve.--Two levels of reserve stand volume per acre were employed in each reproduction method-logging method combination for each volume class. The absolute values, approximated within a few board feet per acre in the actual marking, are as follows:

Volume class	High reserve	Low reserve
	F.b.m. per acre	
I	6,000	4,000
II	11,000	8,000
III	18,500	14,500

Logging Method.--Two sizes of tractors were employed to gage the damage to advance reproduction and to compare logging costs in each reproduction method-level of reserve combination in each of the three initial volume classes. Machines used were D-4 and D-8 caterpillar tractors without bulldozer blades which probably represent the practical extremes of tractor size for logging in the rough southern Idaho terrain.

Stocking and Growth Measurements.--In advance of the logging, hubs (permanently staked points) from which "arms" (0.2 x 1.0 ch.) extended in the four cardinal directions were located randomly in each volume class of the two replicates (16 compartments, or minor drainages). By means of this (sampling) scheme, stocking of seedlings, saplings, and poles, and data for measurement of diameter growth were recorded, thus allowing stand and stock tables, reproduction stock tables, reproduction stocking figures to be computed prior to the first logging and at any subsequent time thereafter.

Sale Contract.--The 4,311,500 f.b.m. of timber involved in the cutting were disposed of by means of an S-25 Sale Contract administered by personnel of the Boise National Forest. Careful planning and fine cooperation between the Intermountain Forest and Range Experiment Station, the Boise National Forest, and the Boise-Payette Lumber Company enabled the project to be carried through virtually as anticipated.

Other Considerations.--In view of the erosibility of the coarse granitic soils of southern Idaho it was considered a good opportunity to measure the effects of skidding under different methods and severities of cutting as it affected soil movement. The Division of Watershed Management is cooperating to the extent of measuring these effects, and has constructed sediment traps on the study area and recorded appropriate data from which deductions could be made regarding rates of soil movement.

Because the mortality of sawtimber affects net growth so substantially, the Divisions of Forest Insects and Forest Disease Research are also cooperating actively in the experiment. Entomologists and pathologists from these divisions are developing criteria which will assist the timber marker in selecting trees which are diseased or which are vulnerable to insect attack.

Several precautions were taken before and during the sale which were believed to be good management practice. The 7.2 miles of logging spur roads were flagged out prior to felling. Grades generally were under 8 percent with steeper pitches up to about 18 percent which resulted in less road construction and soil disturbance than if grade standards had been slavishly observed. Spur roads were kept sufficiently far above the drainage bottoms that a 10-foot strip of undisturbed vegetation lay between the lower edge of the overspill and creekbed to avoid sediment loss.

Fallers were instructed to fell trees uphill or downhill wherever possible to lessen damage to advance reproduction in skidding and to allow safer working conditions for the "Cat" skinners. They were also instructed to bunch their fellings where groups of trees were marked for cutting and to fell all snags over 10 feet high. Cat skinners were instructed to use the same skid trail where possible--thus minimizing damage to potential sawtimber--not to skid down ravines, not to "siwash" turns of logs around saplings and poles, and to avoid all reasonable damage to standing trees regardless of size. No blades on cats were permitted. Before they moved into the woods, each faller and cat skinner was given by the wood's boss a shirt-pocket size tersely worded instruction book explaining the experiment, the numerous tree markings, reminding them of the important sale regulations, and asking their cooperation. Individual compartment maps showing location of marked trees and volume class boundaries were likewise prepared and distributed. These aids proved eminently successful and suggest a means of employer-worker cooperation not yet fully exploited.

On completion of skidding, grass seed was sown on skid trails and slash was treated according to national forest standards except on skid trails where special measures were taken to slow water and soil movement. This slash was placed in piles at intervals. The smaller material of needles and twigs was placed in the deepest part of the skid trail and the heavier limbs placed on top lengthwise with the trails to keep it in contact with the soil. A discretionary standard of number per length of skid trail was adopted depending on grade as follows:

Grade percent:	to 30	31-60	61-90
Spacing of piles-feet:	50	30	10

In a few critical locations where slash was unavailable, cross ditches were shovelled at corresponding distances.

After the logs were removed from the woods, the haul roads were ditched according to arbitrary standards suggested by the Division of Watershed Management as follows:

Grade percent:	0-5	6-10	11-15	15+
Spacing - feet:	100	75	50	25

The spacings of both slash "plugs" and ditches may require modification, the direction of which will be revealed by results of the study. Owing to early frosts in the fall after logging, it was necessary in some instances to construct dikes and leave ditching until spring. This resulted in what appears to be unnecessarily high soil banks on the spur roads.

RESULTS--PRESENT AND FUTURE

It is a common belief, even among many foresters, that useful results from studies such as the one just described, will be many years reaching fruition. This is unfortunate because actually it is not the case. A year since the installation of this experiment in timber production has not passed, and yet worthwhile and applicable information is at hand. Some research techniques employed are new and yet their use greatly decreased the work and demonstrated their possibilities. The practicability of using D-4 tractors on steep ground to move logs which contained up to 3,600 board feet of volume was questioned and yet its performance clearly revealed the advantages and the limitations of this size of tractor for efficient skidding in typical central Idaho topography. It was believed by others that felling up and down hill would result in inordinate breakage, and yet it actually facilitated skidding, made for safer work conditions, and reduced damage.

There is available an excellent sample of virgin forest stand and stock tables covering a 100-percent cruise of trees above 11 inches d.b.h. together with an appraisal of risk by three tree classifications on an 847-acre area. Forest managers can study the resulting stand structure, risk reduction, and risk condition of stands not less than 10 acres in extent that have been cut by two methods of marking two reserve stand volume levels, logged by two different sizes of tractor, in three stands of different initial volumes per acre. Furthermore, these conditions can be examined and compared on the ground. The costs of logging these different stands (16 minor drainages) are known, and the tractor decking arms first contrived by the logger on the D-4 cat and later used on the larger one, has been employed by other operators. It is known that standardized skid-trail "plugs" and logging-road cross ditches are desirable and feasible. Refinements will crystallize these standards.

Within a year, damage and mortality of stems up to 11 inches d.b.h. and the consequent reduction in stocking of young trees will be known accurately. In subsequent years, saw-tree mortality will indicate the efficacy of the marking systems and the levels of reserve used in relation to initial stand volumes. Likewise, knowledge of the stimulation of seed production, the establishment rate of natural regeneration, and the effects of competing vegetation will become available.

After 5 years, comparisons of the effects of the different marking methods on net sawtimber growth will be available as well as accurate data for the growth of stands cut in the different ways. All this information is indispensable for the forest manager if he is to manage this important timber resource for multiple use and full production of wood crops.

FOREST MANAGEMENT RESEARCH

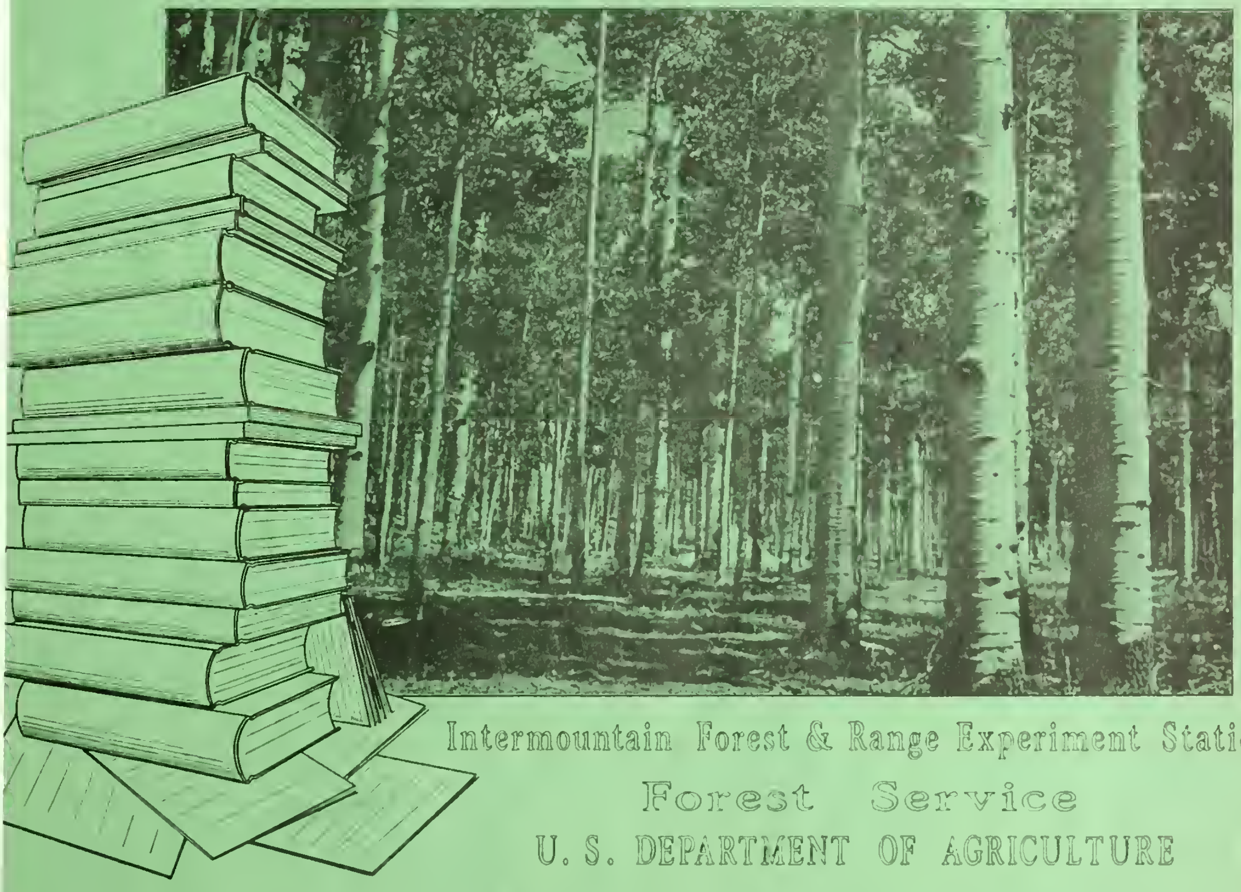
BY THE

INTERMOUNTAIN & NORTHERN ROCKY MOUNTAIN STATIONS

A BIBLIOGRAPHY.

1912 THROUGH 1954

by
James D. Curtis



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By

James D. Curtis[1]

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1/ Forester, Intermountain Forest and Range Experiment Station
Ogden, Utah

FOREWORD

It was planned originally to compile a bibliography of all titles of the Forest Management Division of the Intermountain Station from the inception of research by the U. S. Forest Service in 1912. It was soon realized that this scheme would have its shortcomings because the work of some other divisions is so closely allied with forest management as to be inseparable. The following list, therefore, contains the publications of the Forest Management Division of the Station, together with selected references of other divisions, considered useful to research workers, teachers, students, and forest managers.

The initials INT or NRM after a particular series denote the source before consolidation of the Northern Rocky Mountain and Intermountain Forest and Range Experiment Stations. Initials are deleted for the new series which started with 1954.

An asterisk preceding a reference indicates that none is available for distribution.

Revisions of this bibliography will be made when the number of subsequent publications justify them.

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SILVICS *of* PONDEROSA PINE

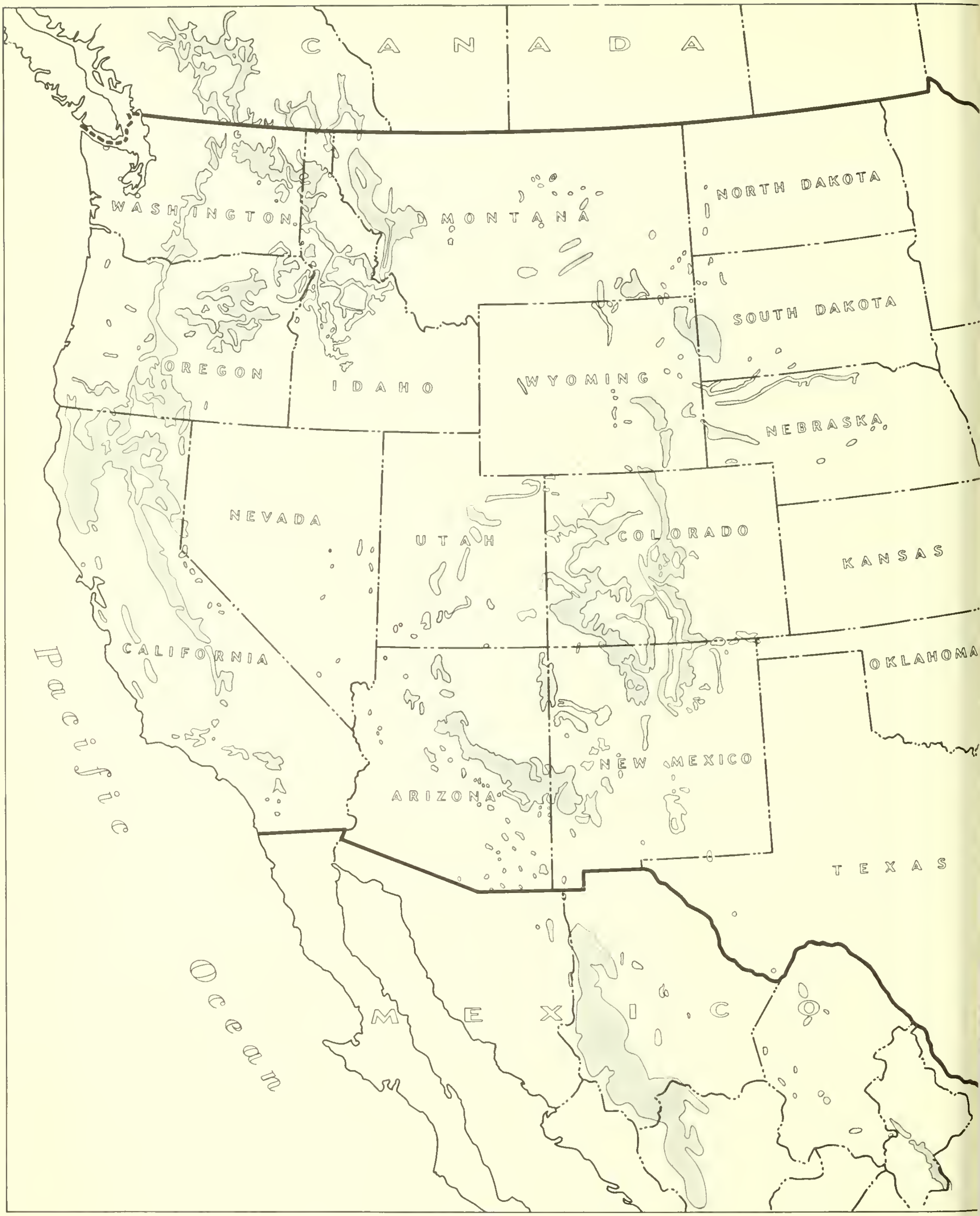

Figure 1.--Botanical range of ponderosa pine (including varieties).

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SILVICS OF PONDEROSA PINE

By

James D. Curtis & Donald W. Lynch
Foresters

INTERMOUNTAIN FOREST AND RANGE EXPERIMENT STATION
Forest Service
U. S. Department of Agriculture
Ogden, Utah
Reed W. Bailey, Director

Foreword

As intensive forest management gradually becomes more common, silviculture will be the means by which the forest will be systematically but carefully manipulated. Silviculture can be really successful only as the silvics of the species are available, appreciated, and applied in the process of removing mature tree crops and starting new ones.

The silvics of the more important North American tree species, as revealed by many years of observation and research, are being collected and published by the U. S. Forest Service experiment stations. This report is one of seven including ponderosa pine, western white pine, lodgepole pine, western larch, western redcedar, grand fir, and black cottonwood being prepared by the Intermountain Forest and Range Experiment Station. Eventually, a single publication that will include the entire series will be issued by the U. S. Forest Service.

The information in this publication is based on selected references and unpublished data through 1956. The authors will appreciate having any omissions or apparent misinterpretations called to their attention.

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SILVICS OF PONDEROSA PINE[1/]

By
James D. Curtis and Donald W. Lynch[2/]

Ponderosa pine (Pinus ponderosa)(76)[3/] is the most widely distributed species of its genus in North America (103) extending from Canoe Creek[4/] on the Fraser River in British Columbia in the north, to Durango, Mexico in the south. It is found from Holt County, Nebraska (21) to the Pacific Coast (103) (fig. 1).

The earliest published account of the species is in the journal of the Lewis and Clark expedition of 1804. David Douglas, the Scottish botanist, recorded it in 1826 as occurring on the Spokane River and a year later sent seeds to the London Horticultural Society from which a tree was raised in the Caledonian Horticultural Society's garden. The first scientific description was by Lawson in 1836 (137). For many years it was called western yellow pine but the name was officially changed in 1932 by the nomenclature committee of the U. S. Forest Service (7) and generally accepted thereafter.

HABITAT CONDITIONS

CLIMATIC

Judged by Thornthwaite's climate classification (140) ponderosa pine is found generally in a subhumid humidity province and a microthermal temperature province characterized by summer rainfall deficiency. For the east slope of the Rockies, the Black Hills, Utah, and the Southwest, however, summer rains are the rule although the Southwest regularly experiences low May-June precipitation. At selected, typical locations in six western states and British Columbia average annual precipitation varies from 10.20 to 21.48 inches, and average growing season precipitation (May through August) from 1.75 to 6.15 inches. Corresponding figures for the Black Hills of South Dakota are about 28.00 and 13.00 inches respectively, but at the Fort Valley Experimental Forest near Flagstaff,

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1/ This statement, in essentially the same form, together with those of other silviculturally important tree species of the United States, will appear shortly as a U. S. Department of Agriculture bulletin.

2/ Foresters, Intermountain Forest and Range Experiment Station, U. S. Forest Service, Ogden, Utah and Boise, Idaho, respectively.

3/ Numbers in parentheses refer to Literature Cited, page 24.

4/ Unpublished data furnished by Research Division, British Columbia Forest Service, Victoria, British Columbia.

Arizona, 6.22 inches of the total growing seasonal precipitation of 7.63 falls in July and August following the May-June dry period. The Skagit valley of northwest Washington and Challenge (U. S. Forest Service Ranger Station) in north-central California where annual rainfall reaches 41.06 inches and 68.80 inches may be two of the wetter areas supporting ponderosa pine in any quantity[4, 5, 6, 7, 8] (112, 147).

The extent of the seasonal rainfall deficiency is better appreciated when it is realized that commonly July and August (May and June in Arizona) precipitation is about 1 inch or less, but that in some places, and frequently in California, it is lacking. Showers that follow early summer droughts probably provide scant moisture useful to young seedlings. In other words, total growing season precipitation figures are misleading and mean little because of the distribution pattern, an unreliable and unpredictable phenomenon.

Regardless of location where ponderosa pine grows, average annual temperatures are between 41.8° and 49.8° F., and average July-August temperatures between 62.0° and 69.6° F. Annual extremes are from -37° to 107° F. [4, 5, 6, 7, 8]

EDAPHIC

Ponderosa pine grows on soils of igneous, metamorphic, and sedimentary origin including quartzite, argillite, schist, shale, basalt, andesite, granite, cinders, pumice, limestone, and sandstone. This results in a variety of soil types (textural classes) including sandy (granitic) loam, gravelly loam, silt loam, clay loam, loamy sand, sandy (basaltic) loam, and gravel on which the species is found throughout its extensive range[4, 5, 6, 7, 8] (14, 111, 157). Depending on the locality and the horizon from which samples are taken ponderosa pine soils have been found to vary from pH 4.93 to pH 9.10[6] (14, 41). Frequently the pH will vary from 6.0 to 7.0 in the surface horizon. Soil samples to a depth of 24 inches in the Boise Basin in central Idaho were found to be

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5/ Unpublished data furnished by Rocky Mountain Forest and Range Experiment Station, U. S. Forest Service, Fort Collins, Colorado.

6/ Unpublished data furnished by Missoula Research Center, U. S. Forest Service, Missoula, Montana.

7/ Unpublished data furnished by California Forest and Range Experiment Station, U. S. Forest Service, Berkeley, California.

8/ Unpublished data furnished by Pacific Northwest Forest and Range Experiment Station, U. S. Forest Service, Portland, Oregon.

largely neutral (pH 6.6 to pH 7.3) in reaction.[9/] The species probably reaches its best development on well-drained, deep sandy, gravel, and clay loams. This is borne out by its performance on such sites (88, 99) and its frequent absence where an impervious substratum exists. This may take the form of associated species encroachment, as the occurrence in certain localities of lodgepole pine in groupwise fashion when good drainage is prevented by the presence of clay subsoil (60). It has also been shown that the texture of the soil mantle, and thus its moisture-retaining capacity, plays an important role in the tree's development, possibly more so than the chemical constituents (59, 111, 138).

On selected areas in Utah, Arizona, Colorado, and Idaho, water-holding capacities of the soil varied from 25.8 to 70.0 percent, and wilting coefficients from 3.3 to 16.1 percent[9/] (14).

PHYSIOGRAPHIC

Ponderosa pine extends from latitude 51°35' N. and longitude 122°-25' W. in the Fraser River drainage of British Columbia to approximately latitude 24°00' N. and longitude 104°45' W. in west-central Mexico, and from latitude 42°30' N. and longitude 99°30' W. in northeastern Nebraska to the Pacific Coast in California. The southernmost range in Baja California is stated to be in the isolated peaks of the Sierra San Pedro Marino (31) but more recent investigations indicate the southern extremity as Julian and San Luis Rey Canyon in San Diego County (43). This may be considered its botanical range. Within this vast area outlined by 15 states, Mexico, and one Canadian province, commercial stands of this valuable species are found in British Columbia, Washington, Oregon, Idaho, Utah, Montana, South Dakota, Colorado, Nebraska, New Mexico, Arizona, California, and Mexico (136, 137, 146).

Ponderosa pine is found at elevations from sea level near Tacoma, Washington (56) to about 9,000 feet in California, Colorado, and Arizona[5, 7/] (111). From north to south throughout its range the species tends to grow at progressively higher altitudes. Although exceptions can be found, the stands of best development occur at elevations of 4,000 to 8,000 feet (depending on latitudinal location) on benches, plateaus, and west and south aspects where the competition from other tree species is not too severe. Such species might include: Douglas-fir (*Pseudotsuga menziesii*), but also lodgepole pine (*Pinus contorta*), western larch (*Larix occidentalis*), white fir (*Abies concolor*), grand fir (*A. grandis*), sugar pine (*Pinus lambertiana*), and incense-cedar (*Librocedrus decurrens*), depending on the forest type.[4, 5, 6, 7, 8/]

9/ Unpublished information. Intermountain Forest and Range Experiment Station, U. S. Forest Service, Ogden, Utah.

"A"

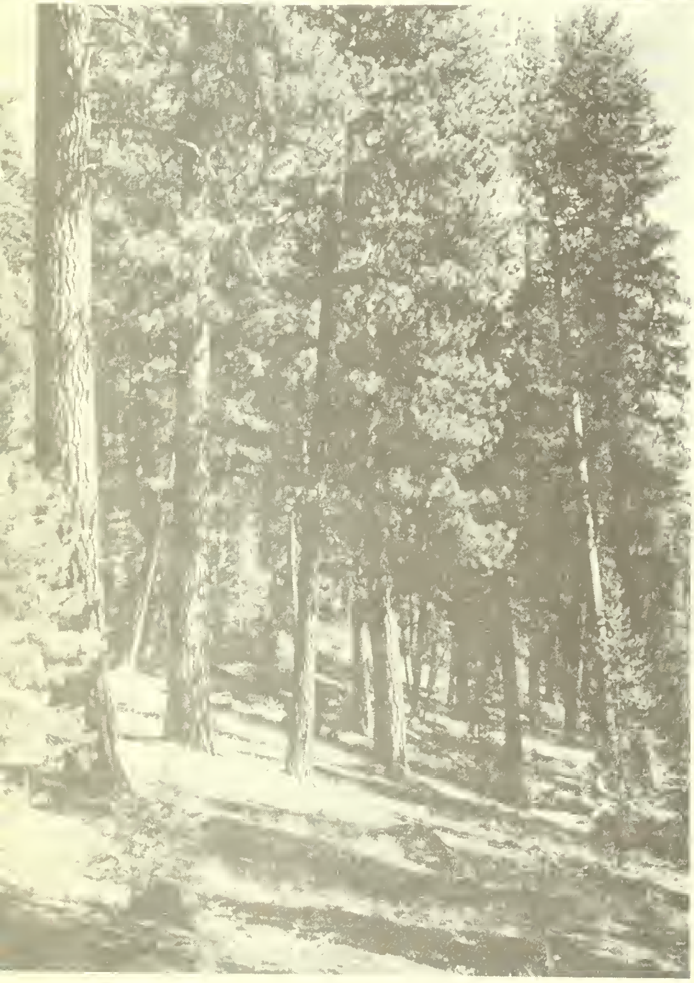

Figure 2.--The ponderosa pine type is commonly composed of many small, even-aged stands, up to an acre or so in size, often pure but sometimes in mixture. In the older age classes, the absence of shrubs and tree seedlings gives the impression of a parklike forest. "A" shows three distinct age classes of trees in a pure stand and "B" a view within one of the older age classes.

"B"

BIOTIC

Ponderosa pine is largely contained within the arid transition zone of the West (85). It may be classed as a component of the Montane Forest, and more specifically the Petran Montane and the Sierran Montane Forests (150). It is further considered the most xeric of the major dominants of this plant association. It is also pointed out that this species forms a consociation and climax unit where it occurs in the pure form or as an association with one or two other tree species, at least over an extensive part of its range (28). Characteristically, ponderosa pine tends to grow in groupwise arrangement of age classes particularly where it occurs in pure stands (fig. 2).

Ponderosa pine can be found as an integral component of five forest cover types in the West including the ponderosa pine--larch--Douglas-fir, interior ponderosa pine, ponderosa pine-sugar pine-fir, Pacific ponderosa pine--Douglas-fir, and Pacific ponderosa pine. The first is typical in western Montana and one in which ponderosa pine never predominates. With cutting or increase in moisture it is easily transformed into either the larch--Douglas-fir type or just the Douglas-fir type (130).

The interior ponderosa pine type comprises the greater part of the area over which the species occurs in eastern Oregon and Washington, Idaho, western Montana, South Dakota, the east slope of the Sierra Nevada in California, Utah, western Colorado, Arizona, and New Mexico. It is frequently found in pure stands and elevationally is the first forest type (sawtimber) of consequence above the desert floor. It is found mingled with Douglas-fir, white fir, western larch, aspen (*Populus tremuloides*), and lodgepole pine towards its upper limits where moister sites prevail by virtue of either aspect or soil conditions. It is commonly a climax type (130).

The ponderosa pine-sugar pine-fir type is often called the "mixed conifer type" in California where it is most extensive on the "west side" of the Sierra Nevada. It is characterized by the predominance of ponderosa pine, sugar pine, white fir, Douglas-fir, or incense-cedar, singly or in combination. The type is found at 3,000 to 6,000 feet elevation and is considered a climax form (130).

The Pacific ponderosa pine--Douglas-fir and the Pacific ponderosa pine types are found in northern California and also in southern Oregon. They are both found with varying numbers of associated species. The former occur typically in the north coast ranges, the Siskiyou Mountains and southern Cascades; the latter on the lowermost west slopes of the Sierra Nevada and southern Cascade range and cross ranges of northern California and southern Oregon. The latter is a climax type; the former is not (130).

Within the ponderosa pine zone of northern Idaho and extreme northeastern Washington, the understory plant cover can be classified usefully by recognizing habitat groups. Thus, four associations (P. P/*Physocarpus*,

P. P./*Symphoricarpos*, P. P./*Agropyron*, and P. P./*Purshia*) are easily discernible in which ponderosa pine predominates and in which it is a major climax species (41).

A variety of vegetation is found in the ponderosa pine type. The following lists are not exhaustive but include the more common woody and herbaceous plant cover found in the different areas where the type occurs:

a. British Columbia: Douglas-fir, *Artemisia tridentata*, *A. tripartita*, *Arctostaphylos uva-ursi*, *Purshia tridentata*, *Symphoricarpos albus*, *Rosa nutkana*, *Crataegus douglasii*, *Clematis ligusticifolia*, *Agropyron spicatum*, *Aristida longiseta*, and *Festuca scabrella*.[4]

b. Western Montana, Idaho, Oregon, and Washington: Douglas-fir lodgepole pine, aspen, *Prunus virginiana*, *P. pensylvanica*, *P. virginiana* var. *melanocarpa*, *Artemisia tridentata*, *Chrysothamnus nauseosus*, *Ceanothus velutinus*, *Symphoricarpos rivularis*, *Amelanchier alnifolia*, *Purshia tridentata*, *Rosa spaldingi*, *R. ultramontana*, *Spiraea betulifolia*, *Berberis aquifolium*, *Physocarpus malvaceus*, *Calamagrostis rubescens*, *Festuca idahoensis*, *Stipa columbiana*, *Koeleria cristata*, *Bromus tectorum*, *Balsamorhiza sagittata*, and *Carex geyeri* [6, 8] (41).

c. California: Douglas-fir, white fir, incense-cedar, sugar pine, Jeffrey pine (*Pinus jeffreyi*), tanoak (*Lithocarpus densiflorus*), madrone (*Arbutus menziesii*), California black oak (*Quercus kelloggii*), *Chamaebatia foliolosa*, *Arctostaphylos patula*, *Ceanothus cordulatus*, *C. prostratus*, *C. parvifolius*, *Castanopsis sempervirens*, *Stipa elmeri*, *S. occidentalis*, *Carex rossi*, *Festuca idahoensis*, and *Sitanion hystrix*.[7]

d. Colorado and the Black Hills: *Bromus tectorum*, *Bouteloua gracilis*, *Festuca arizonica*, *Agropyron smithi*, *Muhlenbergia montana*, *M. torreyi*, *Danthonia spicata*, *Geranium fremonti*, *Sporobolus heterolepis*, *Koeleria cristata*, *Poa pratensis*, *Allium cernuum*, *Fragaria americana*, *Galium boreale*, *Artemisia frigida*, *Purshia tridentata*, *Populus tremuloides*, *Prunus virginiana*, *Rosa macounii*, *Opulaster intermedius*, *Amelanchier alnifolia*, *Symphoricarpos occidentalis*, and *Arctostaphylos uva-ursi*.[5]

e. New Mexico and Arizona: Gambel oak (*Quercus gambeli*), *Achillea lanulosa*, *Thalictrum fendleri*, *Lotus wrighti*, *Vicia americana*, *Senecio spartioides*, *Actinea richardsoni*, *Muhlenbergia montana*, *Bouteloua gracilis*, *Festuca arizonica*, *Blepharoneuron ticholepis*, *Sitanion hystrix*, *Agropyron smithi*, *Sporobolus interruptus*, and *Koeleria cristata* (110).

LIFE HISTORY

SEEDING HABITS

Flowering and fruiting.--Based on available records taken over periods from 3 to 10 years in the five regions where ponderosa pine is found, there appears to be at least as much intraregional as interregional variation for a specific phenological response. In western Montana, central Idaho, and eastern Oregon, at elevations from 3,000 to 6,000 feet above sea level, flowering generally starts May 1 to 10. Female conelets nearly 1 inch long appear May 5 to June 10, pollen is shed May 25 to June 15, cones reach full size July 20 to August 10 of the following year, seed is ripe August 20 to September 5, cones begin to open September 1 to 13, and seed is shed until November.[6, 7, 8] On the east and on the west side of the Sierra Nevada in California at 6,000 feet altitude, cone development takes place about 2 weeks later (51). In ponderosa pine stands on the west side of the Sierra Nevada in California, cones did not open on the trees until their specific gravities had dropped below 0.62 (127). In northwest Montana, 5.4 percent of total seed production fell from October 30 of one year to May 2 of the next year (133) but occasionally seed is retained an even longer time (105). In Colorado at 8,900 feet studies over a 9-year period disclosed that carpellate flowers emerge on or about June 18 and that only about 36 percent of them survive at the beginning of the second year. Their initial emergence is closely correlated with the passing of freezing weather (120). In the California pine region, trapping indicated that seed fall was complete by the middle of November (51).

In California on the west slopes of the Sierra Nevada, pollen was collected as early as April 15 at 39° N. latitude and 121° W. longitude at 3,000 feet but May 11 was found to be a fair average date over a 7-year period. For this locality it is estimated that a mean interval of 8 days per 1,000 feet difference in elevation can be considered safe for purposes of pollen collection (42).

In common with most other pines, ponderosa pine cones require 2 years to mature, or specifically, about 26 months (120). The species is monoecious having male and female flowers on the same tree (56).

It has been found that fertilization in the cone ovules takes place when the seed is full grown and within a few days, some 13 to 14 months after pollination. Embryonic selection requires 34 to 36 days, embryonic differentiation 10 to 12 days, and seed maturation 40 to 45 days (24). The larger the seed the larger the embryo and the greater the number of cotyledons but there is no correlation between seed size and cone size although a tendency in this direction exists. The number of cotyledons will be found to vary between 6 and 14 (25). Inherent vigor is not correlated with, or transmitted by weight of seed, but weight differences between seeds of ponderosa pine are largely due to the weight of seed coat and endosperm (115).

Seed production.--No periodicity, as such, has been observed in the seed production of ponderosa pine. In California ponderosa pine forests medium seed crops are borne on an average of every 2 years although the average interval between very heavy cone crops is 8 years (51). Observation over 23 years shows the species to be a poor seeder west and a fair seeder east of the Continental Divide in Montana with only one "good" crop occurring (22). The species bears cones at as early as 16 years, which is close to the minimum age for conifers (27) and will continue to produce seed with acceptable viability when 350 years old (37). Seed from trees of 60 to 160 years has been found to possess greater viability than that from younger or older trees (113, 143). In California trees over 25 inches diameter breast high were the best producers (51). In central Idaho, mature and overmature trees at 5,500 feet elevation produced lower quality seed than similar trees at 4,000 feet (143), and open grown trees produced heavier crops of larger cones than stand grown trees (142).

Recent studies indicate a relationship between the total average monthly temperatures for April and May of the year flower buds are formed and the cone crop response 27 months later. Temperatures above normal presage abundant flowering the following spring; temperatures below normal result in few flowers the subsequent year (83).

The insects which do most damage to cones and to seed development are probably *Conophthorus ponderosae* and *Megastigmus albifrons* (63) and may account for considerable loss in years of small cone crops.

Many birds and mammals, including the white-breasted nuthatch (*Sitta carolinensis*), red-breasted nuthatch (*S. canadensis*), longcrested jay (*Cyanicitta stelleri diademata*), Steller's jay (*C. stelleri*), red-shafted flicker (*Colaptes cafer*), junco (*Junco phaeonotus dorsalis*). house finch (*Carpodacus mexicanus*), redpoll (*Acanthis linaria*), red crossbill (*Loxia curvirostra*), Clark's nutcracker (*Nucifraga columbiana*), white-headed woodpecker (*Dryobates albolarvatus*), black-capped chickadee (*Penthestes atricapillus*), Great Basin white-footed mouse (*Peromyscus maniculatus sonoriensis*), Columbian white-footed mouse (*P. maniculatus artemisiae*), thick-footed mouse (sp. ?), pocket mouse (sp. ?), buff-bellied chipmunk (*Eutamias amoenus luteiventris*), western chipmunk (*E. minimus*), pine or red squirrel (*Tamiasciurus hudsonicus*), California gray squirrel (*Sciurus griseus*), Douglas squirrel (*T. douglasii*), silver gray squirrel (*S.* sp.), Abert squirrel (*S. aberti*), Kaibab squirrel (*S. kaibabensis*), Arizona mantled ground squirrel (*Citellus lateralis arizonensis*), and golden-mantled ground squirrel (*C. lateralis*) all consume seed, sometimes in impressive quantities (20, 124), either in the tree or on the ground[8/] (2, 4, 34, 111, 132, 133, 139). In fact, the red or pine, Kaibab, and Abert squirrel destroy prospective cone crops by their vigorous clipping of cone-bearing twigs carrying potential flowers and/or conelets (4, 111, 132). Hence, it is conceded that certain rodents and birds can substantially affect, directly and indirectly, the seed crop in years of low and fair production (34, 111, 132).

In central Idaho ripe cones had a specific gravity of .80 to .86, varied in mean maximum diameter from 1.72 to 1.90 inches and in length from 3.20 to 3.89 inches, and averaged 64 to 92 seeds per cone (142). Generally cones have been found to range from 1.5 to 2 inches in diameter and 2.75 to 5.75 inches in length (51, 137). Cleaned seed per pound varies from 6,900 to 23,000 and averages 12,000. One bushel of cones will produce 9 to 32 ounces of clean seed and 100 pounds of fresh cones will yield 2 to 7 pounds of clean seed. Germinative capacity varies widely but usually averages close to 60 percent (145).

In central Idaho for selected dominants, the mean number of seed per tree for a single year ranged from 16,100 in 70-year-old second-growth at 5,500 feet elevation to 118,300 in virgin overmature stands at the same elevation (142). In California, over a 16-year period, trees over 50 inches d.b.h. averaged 300 cones per tree.[7/] Ponderosa pine seed will retain a high fraction of its original viability if suitably stored (in air-tight containers at 32° F.) (37, 123, 125) but has sprouted during stratification at 36° F. (126). Delayed germination for 1 year has been recorded for the species (37).

Seed dissemination.--The character of stand will largely determine for a given year how many ponderosa pine seeds will reach the ground. In central Idaho 254,000 per acre were recorded for virgin forest, 203,000 per acre in a selectively cut forest (with a residual stand of 4,047 f.b.m. per acre) and 243,000 in a 70-year-old second-growth forest as early as September 15 (144). Seed was produced at the rate of 104,000 per acre in a partially cut stand in western Montana (133). Very little seed is carried more than 100 feet from the edge of timber (144). As a general rule, the heavier the seed, the more rapid the fall but many exceptions to this occur because the size, shape, and curvature of a seed wing varies within a species; indeed, seed size and wing size vary between sizes of cones and the position of the seed in the cone. Ponderosa pine seed with an average weight of .058 gram fell in still air at an average rate of 5.0 feet per second (129). In California, it is estimated that "under average conditions, probably very little seed is scattered more than about 300 feet" (51).

VEGETATIVE REPRODUCTION

Ponderosa pine does not reproduce naturally by vegetative means, although two instances of root inducement (from callus formation after wounding the branch of a young growing tree and surrounding it with damp sphagnum moss enclosed by tightly secured polythene wrapping) are on record.[10/] Propagation of the species by cuttings has been accomplished but is considered still in the experimental stage. The age of the tree from which cuttings are collected and the location of the sample branch in relation to the leader, the time of year, the physiological condition

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10/ Intermountain Forest and Range Experiment Station unpublished report, 1953.

of shoots, the temperature of the rooting medium and the relation between temperature of the atmosphere and that of the rooting medium, all affect the success of root propagation. Success in rooting, using various media and treatments, has varied between 0 and 68 percent (93).

Ponderosa pine has also been propagated vegetatively by grafting. The methods of grafting seedlings on transplants, seedlings on seedlings, shoots of older pines on nursery transplants, single needle bundles, and by approach (inarching) were all used experimentally. A total of twenty successful intraspecific grafts of the genus *Pinus* was achieved. Ponderosa pine was used as the scion in three cases and as the stock in fifteen (91).

SEEDLING DEVELOPMENT

Establishment.--Throughout its range, excepting the Black Hills, ponderosa pine reproduces spasmodically, which is widely construed as the result of the fortuitous combination of a heavy seed crop followed by an above average rainfall during the growing season. Available evidence (31, 35, 50, 72, 111, 112, 118, 141, 144, 157) indicates that soil moisture is the critical factor of survival. Because of this fact, it follows that soil texture, plant competition, and condition of the seedbed exert decisive influence--separately or collectively--in the survival of the very young seedling. The extent and effect of these influences have been examined, measured, and interpreted[8/] (11, 39, 54, 61, 102, 111, 141, 144, 150). There is some evidence that seedlings benefit from the proximity of moisture-holding and nitrogen-fixing plants (31, 101), but these instances, unfortunately, are the exception rather than the rule.

Because there is less competition and more soil moisture on burned areas compared to virgin forest, the roots of 1-year-old seedlings penetrate deeper and have more laterals on the former than on the latter (141).

In these early stages of the seedling's life certain factors become critical, militating against its normal development, and commonly cause mortality. The cutworm (*Euxoa excellans infelix*) can cause appreciable (in one instance 28.6 percent) damage to seedlings (47). During open winters 1- and 2-year-old seedlings can suffer damage and mortality from frost (55, 157). Certain rodents and birds destroy young seedlings[8/] (139).

It has also been shown that 1- to 3-month-old seedlings are killed by stem temperatures of about 130° F. and greater (12, 142). To produce this lethal stem temperature, at least under laboratory conditions, required an average, surface (sand) temperature some 21° higher, or about 150° F. (12). Ponderosa pine is more successful in resisting high soil surface temperature with increasing age than its competitors so that when 110 days old seedling stems can successfully withstand instantaneous temperatures of 136° to 180° F. (119). Evidence also indicates that at elevations of 2,760 feet above sea level and on level ground, soil surface temperatures reach 162° F. in July and as high as 136° F. as late as October 15, in the ponderosa pine type in California (82). The striking and substantial effect of shade on soil surface temperatures has also been demonstrated (12, 82).

Where there is high humidity, heat injury to young seedlings increases with increased temperature. Under ordinary atmospheric conditions it is believed that resistance increases due to the cooling effect within plant tissues produced by transpiration (18). In the light of more recent research on the subject, this resistance can also be accounted for by the physical processes of conduction, radiation, or convection (86).

Ponderosa pine is a more extravagant user of readily available moisture than Douglas-fir, Engelmann spruce, or lodgepole pine, but the nourishment in the large seed and its innate ability to send down a fast-growing taproot (fig. 3) enables it to survive on and dominate the more exposed sites or other sites where competition is not high (15). It also possesses the ability as a seedling to withstand prolonged drought (high soil moisture stress) with soil moisture content very close to, or even below, the permanent wilting point (49, 109). Furthermore, under laboratory conditions, it has been determined that dew at night can possibly contribute to survival of ponderosa pine seedlings growing on typical sites where the wilting point of the soil has been reached, usually late in the growing season (135). Thus, by virtue of these characteristics, its lower altitudinal limits are extended beyond those of other associated species (40).

Some observers feel that, because of organized fire protection, a natural thinning process has largely disappeared. It is pointed out that, as a result, dense, even-aged, stagnating stands of the species have developed. Furthermore, the invasion of associated species such as white fir, Douglas-fir, and incense-cedar have crowded out the advance reproduction and weakened the overstory of ponderosa pine thus making it a prey for insects (149). Antithetically, it is believed by others that in the past fire has been instrumental in prompting the typical groupwise occurrence of small even-aged stands in this species (111, 151).

In view of these observations, it is thought that a method of reproduction that creates openings with thoroughly scarified soil and large enough to provide overhead and some side light, yet in some measure furnishes shade from marginal trees would result under average conditions, in at least some regeneration. It is conceivable that some form of shelterwood would also succeed but only where July-August precipitation can provide sufficient soil moisture (perhaps about 3.00 inches) to offset that used by the overstory and the vegetation which may invade

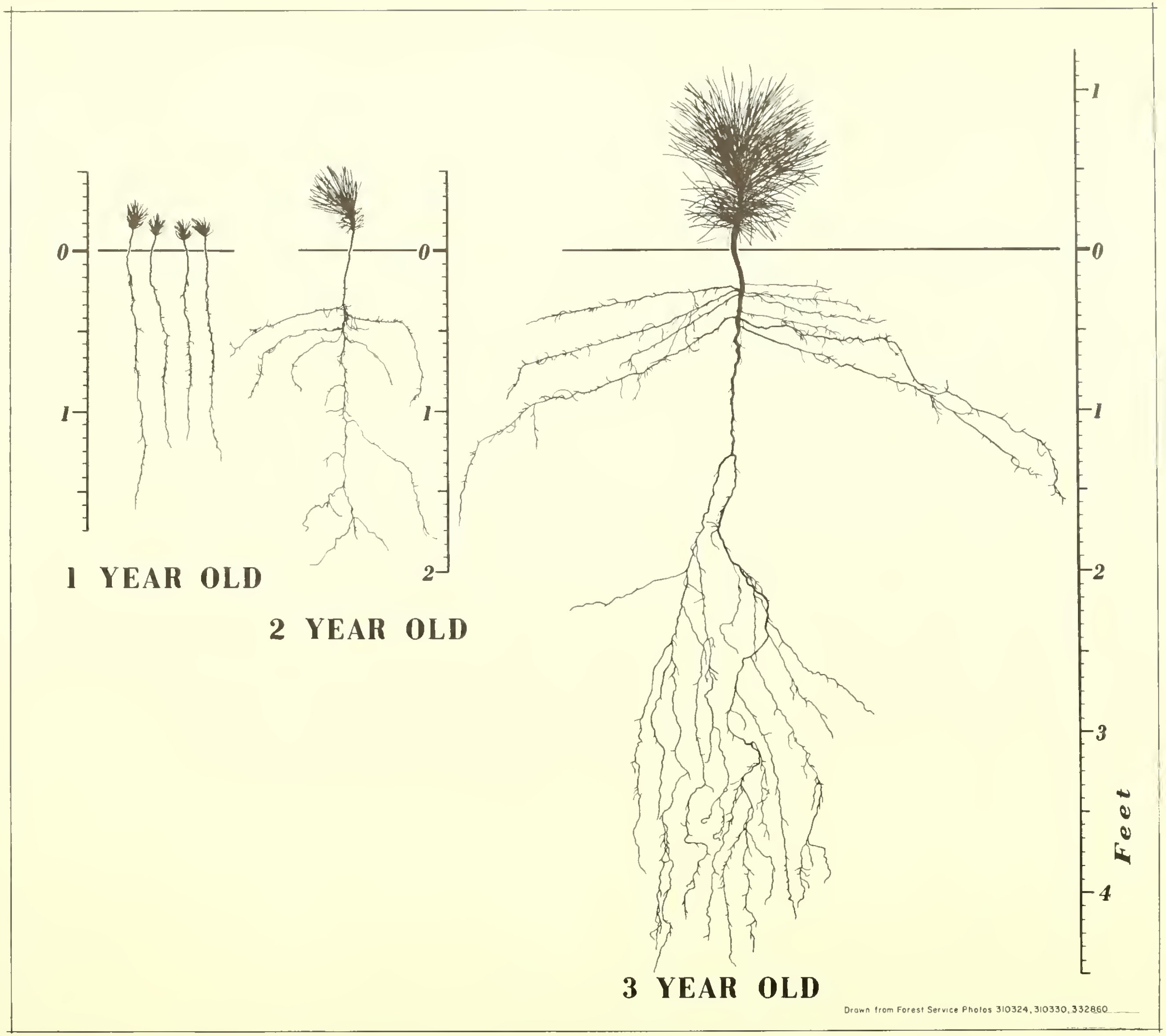

Figure 3.--The development of the seedling root system from initial taproot to one with high and low spreading laterals is illustrated here. First-year seedling taproots as long as 51 inches have been recorded where the growing tip met no obstructing soil layers.

the stand. Considering the systems that have been tried,[11] however, and the success attending them, it is probable that on areas to be reproduced, even though a seed source and mineral soil seedbed are available, some artificial regeneration will be necessary for acceptable stocking in due time in ponderosa pine management.

Early growth.--The ability of ponderosa pine seedlings to send down a vigorously growing taproot has been given as a reason for its tenacity on severe site where its associates often fail (15). Roots of 1-year-old natural seedlings are known to reach average lengths of 22.4 inches (average top height of 2.8 inches) and 4-year-old seedlings an average maximum of 60.7 inches (average top height of 12.3 inches) on southerly aspects on cutover areas (142). Nevertheless, seedling mortality can be exceedingly heavy (89 percent) during the first year in selectively cut stands (143).

In central Idaho losses attributed to fungi were greater in shade and on north slopes while mortality from insolation was greater in the open and on south slopes. At depths below 6 inches, soil moisture remained above the wilting point on areas free of competing vegetation throughout the growing season but dropped to or below that critical point on most vegetated plots (144). The importance of competing vegetation as a deterrent to early survival and development of young seedlings has been clearly demonstrated in the Southwest (111).

On undisturbed soil, seedlings grow slowly during the first few years of establishment and require full light for best development. Normal growth is hindered by less than 40 percent of full sunlight, but later the form and quality of seedlings are profoundly affected by the amount of side shade they receive (111). Other workers have determined that minimum light requirements vary between 1.60 and 17.0 percent (the former an intensity rarely encountered in pine forests), but point out that soil moisture, and indirectly plant competition and soil texture, play an inseparably allied part in the minimum amount of light the species can endure (16, 26).

Although ponderosa pine seedlings can withstand overstory shade and root competition for as long as 40 years, it is considered an intolerant species (13). The idea has also been advanced that ponderosa pine stands may occur in groupwise fashion by virtue of the tree's intolerance (68).

In central Idaho root growth of 1-year-old seedlings was found to continue throughout the summer in both burned areas and virgin stands, but top growth stopped by August 1 (141). In the seedling stage, ponderosa pine because of its deep root system, even under conditions

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11/ Curtis, James D., and Wilson, Alvin K. A test of group selection in Idaho ponderosa pine. Intermountain Forest and Range Experiment Station. (In preparation.)

exposed to wind, is able to maintain a more uniform transpiration rate than, for example, lodgepole pine. It is, therefore, not likely to experience soil moisture fluctuations at the depth to which it penetrates (52) and thus has a distinct advantage over some of its shallower-rooted associates.

On the western slopes of the Sierra Nevada, variation has been found among tree species in the start of seasonal growth. Height growth of ponderosa pine started very significantly later with each rise of 2,000 feet in elevation, and the length of the growing season was shorter significantly with a 3,000-foot increase in elevation. Likewise, radial growth started significantly later with a 2,000-foot increase in elevation. Rates of height and radial growth did not vary with elevation during the grand period of growth. At 5,000 feet elevation a 6-year-average showed that ponderosa pine started radial growth on March 23 and height growth on April 26. The former period lasted 177 days; the latter, 97 days (48).

The depredations that plague the formation, ripening, and safety of seed continue after seedling establishment and during early growth. The meadow mouse (*Microtus* sp.), deer mouse (*Peromyscus* sp.), gray-collared chipmunk (*Eutamias cinereicollis cinereicollis*), Oregon ground squirrel (*Citellus richardsonii*), golden-mantled ground squirrel (*C. lateralis*), pocket gopher (*Thomomys talpoides*), wood rat (*Neotoma cinerea*), rabbits (*Lepus* and *Sylvilagus* sp.), porcupine (*Erethizon epixanthum*), antelope (*Antilocarpa americana americana*), white-tailed deer (*Odocoileus virginianus macrourus*), and mule deer (*O. hemionus hemionus*) feed to a greater or lesser extent on seedlings (1, 3, 17, 32, 111, 114, 139, 156).

Discouragingly enough, but fortunately in isolated instances only, deer can virtually eliminate advance reproduction from the stand (104). Only judicious regulation of grazing can effectively reduce excessive damage to natural and artificial reproduction from sheep and cattle by browsing, trampling, and bedding (111, 131).

Although trees in the sapling and pole stage are less likely to be fatally affected than seedlings, they nevertheless do not escape destructive agencies. Red, Abert, and Kaibab squirrels and porcupines attack saplings and poles and while rarely killing them, produce disfigurement in the stems on which they feed (38, 111, 114).

Uncontrolled fire in central Idaho was found to destroy 87.5, 85.6, and 61.2 percent of the reproduction in virgin, cutover, and young growth stands respectively (30). Even controlled burning has been found exceedingly lethal to the youngest age classes.[12]

12/ Gaines, Edward M., Kallander, Harry R., and Wagner, Joe A. Controlled burning in southwest ponderosa pine: results from the Blue Mountain plots, Fort Apache Indian Reservation. (To be submitted to Jour. Forestry for publication.)

Ordinarily each season, ponderosa pine, by normal physiological processes, develops hardiness to severe winter temperatures (107), but occasionally can suffer "winter killing" of foliage if sudden temperature inversions occur. Likewise, lethal gases can damage the foliage of immature and mature trees (79, 128).

Snow can result in damage to saplings and poles particularly where high stand density has resulted in supple stems and low crown-tree height ratios (111, 142). The engraver beetle (*Ips* spp.) kills sapling and pole-sized trees and can cause extensive damage in young stands (63).

SAPLING STAGE TO MATURITY

Growth and yield.--Ponderosa pine grows to impressive size, and while stems 103.5 inches in d.b.h. (9) and 232 feet in height (56) have been recorded, diameters of 30 to 50 inches and heights of 90 to 130 feet are common throughout most of its range. It often reaches ages of 300 to 500 years in overmature stems, but 726 years have been accurately determined in eastern Oregon (64).

As an example of the yields of ponderosa pine, table 1 shows a representative section from a normal yield table (87), for sites 70 to 100. The full range of site indices for ponderosa pine extends from 40 to 160; site index here refers to height in feet for dominant stand at age 100. Typical stands are irregularly stocked; thus the use of normal yield tables over any sizable area is difficult. The yields in

Table 1.--Board-foot volume 1/ per acre, Scribner rule of trees 11.6 inches and larger in diameter

Age (years)	Volume per acre by site index 2/			
	70	80	90	100
110	16,200	23,100	31,100	40,600
120	19,000	26,200	34,700	44,600
130	21,500	29,000	38,000	48,300
140	23,700	31,500	40,900	51,700
150	25,700	33,800	43,600	54,800
160	27,500	35,900	46,100	57,600
170	29,200	37,800	48,400	60,100
180	30,900	39,600	50,500	62,400

1/ In 16-foot logs to 8-inch top, exclusive of 2-foot stump, measured to nearest 100 board feet.

2/ Site index defined as height in feet for dominant stand at age 100 years.

table 1 should therefore be reduced, because of the common understocking that exists in natural stands, by percentages of 50 or more even for the "well-stocked" condition (33). Typical stands contain fewer stems with larger average diameters than those shown in normal yield tables. However, exceptions to this can be found in restricted areas on poorer sites where overstocking often results in a stagnation of growth. In the Southwest, more extensive areas of overstocked stands exist, particularly in the sapling and pole sizes.

On excellent sites, ponderosa pine is capable of growing at exceptionally fast rates. Growth of young stands on small plots in bottom land areas of northern Idaho was found to average more than 1,000 board feet per acre per year over a 17-year period (80). More typical of average growth of young trees, however, are the rates shown (81) for stands in the Inland Empire. Table 2 gives a portion of a growth table from this study for a 10-year period by diameter and age classes.

Table 2.--Future 10-year volume growth per tree in cubic feet for average sites[1/]

	Age in years			
	40	50	60	70
Inches	Cubic feet			
8	3.50	2.38	1.80	1.46
9	5.40	3.77	3.00	2.50
10	7.45	5.25	4.20	3.63
11	10.40	6.70	5.30	4.50
12	-	8.90	6.95	5.90
13	-	11.20	8.80	7.50
14	-	-	10.30	8.80
15	-	-	12.60	10.70

1/ Includes stump and top without bark.

Heights attained at various ages are shown in figure 4 for several site indices (88). These cover the average range of conditions throughout the ponderosa pine type.

Old-growth ponderosa pine produces excellent, high grade lumber, but young trees are typically limby and natural pruning develops slowly (fig. 5). An average clear length of 11.5 feet has been recorded in stands 250 years old in central Idaho (142). While natural pruning is mostly due to the effect of shade and mechanical forces of nature, an instance is cited in Arizona where the process of branch dying and disintegration was largely due to disease (78).

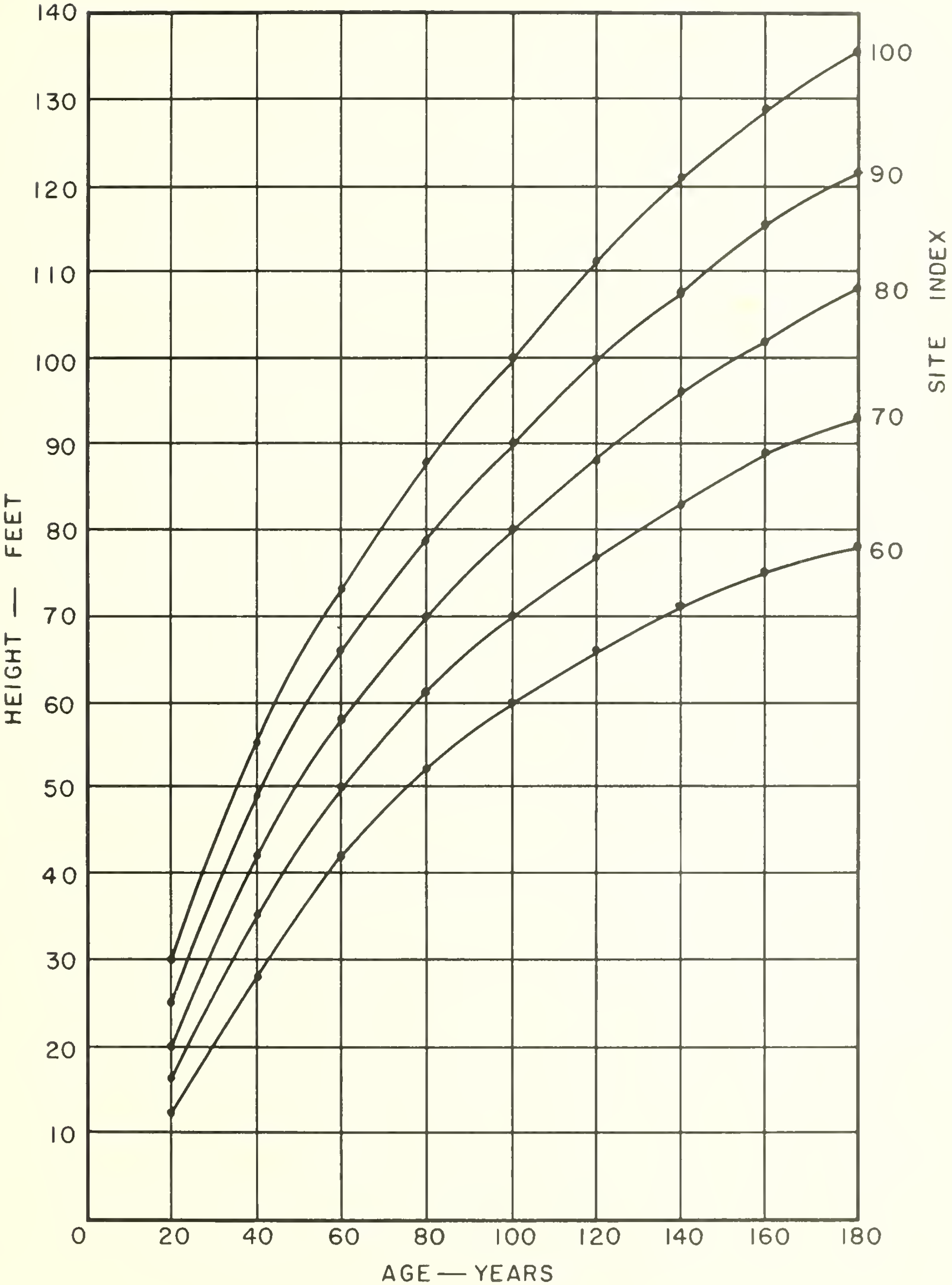

Figure 4.--Heights of the dominant stand of ponderosa pine by ages for site indices 60 to 100 (after Meyer).

Figure 5.--Ponderosa pine is slow to lose its branches as demonstrated in this 80-year-old stand. Artificial pruning will be necessary to produce clear lumber during the 160-year rotation contemplated for the species.

Release.--Ponderosa pine has the ability to respond to release, regardless of age, by increased diameter and/or height growth (36, 45, 69, 70, 87, 98, 111). It is generally accepted that this trait of the species, at least in the older stems, exerts itself largely as a result of increased moisture supply rather than crown expansion, because otherwise the response would not be so sudden although it could be as great. It is noteworthy that this response is manifested even in the oldest (class 4) and the least vigorous (class D) of Keen's tree classes (36, 65).

INJURIOUS AGENCIES

Insects.--From the sapling stage to maturity, ponderosa pine is subject to attack by many kinds of insects. They may attack any part of the tree, from the seeds in the cones to the main trunk. They may reduce the vigor and make the tree more susceptible to attack by other insects, reduce the rate of growth, deform the stem, or kill the tree outright. There are 108 species listed that attack the previously recognized Pacific Coast form and 59 species that attack the previously recognized Rocky Mountain form (63). The appearance, age, and condition of trees has been used as a basis for their susceptibility to insect attack (65, 121).

The most important of the tree-killing insects are several species of *Dendroctonus*. The western pine beetle (*D. brevicomis*) is a common cause of mortality in overmature, decadent, or unvigorous trees. When optimum conditions prevail, it can kill apparently healthy trees of all age classes (155). The Black Hills beetle (*D. ponderosae*) is the most aggressive and destructive enemy in the central Rocky Mountain Region. During the 1895-1908 outbreak in the Black Hills of South Dakota, this insect killed between 1 and 2 billion board feet of ponderosa pine (19). The mountain pine beetle (*D. monticolae*) is an equally aggressive insect but perhaps not quite as frequent in attack (46). *D. barberi*, *D. convexifrons*, and *D. valens* are additional important species of the genus.

Many additional species of bark beetles and flatheaded and roundheaded borers attack ponderosa pine. Most of them enter trees killed or weakened by other agents; but thrifty, vigorous trees are not always immune to attack by some species.

Several defoliating insects such as the pine butterfly (*Neophasia menapia*), the pandora moth (*Coloradia pandora*), and sawflies (*Neodiprion* spp.) periodically cause damage over extensive areas, an example of which was the recent outbreak of the pine butterfly in central Idaho (106).

Tip moths (*Rhyacionia* spp.) often cause terminal and branch killing on saplings, and thus deform the stems. Many kinds of scales, aphids, and other sap-feeding insects can reduce the vigor of the host and thus make it susceptible to additional attack.

Because great volumes of overmature trees are not yet harvested, the *Dendroctonus* beetles are currently considered the most damaging insect, but as this age class of tree is gradually removed, it is possible that other insects may become more important.

Diseases.--A number of pathogens attack ponderosa pine and either kill the host or result in serious defect. One of the more insidious, whose identity is difficult to detect by virtue of its life cycle, is a root and butt rot, *Fomes annosus*. It attacks all ages of trees and, in the case of stems other than small ones that die, is often mistaken for the work of Dendroctonus beetles which invariably follow the killing of the cambium near the ground level (148).

Polyporus anceps is the major defect from disease in merchantable stands of ponderosa pine in Arizona, New Mexico, and the Black Hills of South Dakota. It gains access to its host through dead branches and may result in a 15-foot column of rot at 150 years of age which involves considerable cull (6).

A serious parasitic destroyer and deformer of the species is dwarf-mistletoe, of which there are two species, Arceuthobium vaginatum forma cryptopodum in the Southwest, and A. campylopodum forma campylopodum in California and the Northwest. It is one of the three major causes of timber mortality in Arizona reaching as much as 16,000,000 board feet annually. Seed can infect trees up to 70 feet distant (53, 67).

Elytroderma deformans, first observed in parts of Idaho, Washington, and Montana in 1913 and described shortly thereafter (154), is found over the entire commercial range of ponderosa pine. It is a serious needle blight capable of slowing growth and killing trees of sawtimber size. Bark beetles are prompted to attack infected trees (75). Severe damage has been reported from the Ochoco National Forest in Oregon where from 1946 to 1950, some 90 percent mortality occurred in areas of severest infection and where 98,148,000 board feet of dying and dead trees were removed (74).

Additional pathogens to which ponderosa pine is subject are the blister rusts. The paintbrush blister rust (Cronartium filamentosum) common in the Southwest (111) and in southern Utah (89) may attack the base, middle, or top of the tree crowns, and spread upward and/or downward rather slowly, eventually killing many merchantable stems. The western gall rust (C. coleosporioides) can be destructive to seedlings and saplings by deforming or killing them (23). It has been found to kill occasional trees and deform larger stems in a 50- to 175-year stand in an isolated area of western Montana (73). C. comandrae (C. pyriforme) produced understocking in seedling, sapling, and pole-sized trees in northeastern California (84).

Fire.--It is common to find basal fire scars on the thick-barked stems in old-growth ponderosa pine forests (fig. 6), and judging from the callus growth on some of these wounds, light uncontrolled fire must have been common before the advent of the white man. In a 45,000-acre conflagration in central Idaho, fire destroyed, and fatally damaged, 73.0, 74.0, and 54.0 percent of the volume in virgin, cutover, and young growth stands respectively (30). Studies on the Modoc National Forest in California revealed extensive but less damage by fire scarring to ponderosa pine than to incense-cedar and also fewer enlargements of old fire lesions (71). In a 1,500-acre burn in Arizona on an area which had been cut by the group selection method and which was a combination of surface and crown fire, no poles and only 5 percent of sawtimber-size trees were living 6 years after the fire where more than 60 percent of the crown

Figure 6.--In old-growth ponderosa pine forests, few mature and overmature trees are without basal fire scars. They are usually not as high as the one shown here but invariably exhibit the effects of more than one surface fire by the presence of successive layers of callus growth on their perimeters.

had been destroyed. From this study it is considered that trees of any size with more than 60 percent of their crown destroyed are poor risks (58).

Considering relative fire resistance of the various species at a mature age, it has been estimated that for the 11 most silviculturally important conifers of the Northern Region, ponderosa pine ranks second, and is indicated as "very resistant," exceeded only by western larch. For 13 important conifers of Oregon and Washington, it is rated third behind western larch and Douglas-fir (134).

Wind.--Because the initial taproot of ponderosa pine generally persists throughout its life, together with strong laterals extending eventually from the base of the tree as far as 100, and occasionally 150 feet (157), it is usually considered a windfirm species. When windthrow does occur it is often because root rots have weakened the tree's stability. In order of decreasing resistance, the species has been listed second out of 10 of the most important Northern Region coniferous species and is exceeded only by western larch.13/ Wind and lightning are nevertheless the two most serious sources of damage to trees of sawtimber size (especially over 30 inches d.b.h.) in the Southwest (111) where, on limestone sites, the root systems are apparently shallow.

13/ Marshall, Robert. Natural reproduction in the western white pine type. Ms. Inland Empire Research Center, U. S. Forest Service, Spokane, Wash. 1928.

SPECIAL FEATURES

Ponderosa pine derives its name from the ponderous bulk of the tree and the weight of the wood sawn from it (76). Phylogenetically it is considered a younger form than Jeffrey pine if its distribution and iodine content are used as criteria (90). Western Indians are reported to have found the living cambium layer sweet and nutritious (8).

The leaves of ponderosa pine are bluish-green or grayish-green and occur in bundles of three (occasionally of two or four and exceptionally of five). Each season's growth of leaves remains on the tree about 3 years (29, 137). It has been found that certain anatomical and morphological features of the needles differ strikingly depending on the age of the tree, the exposure, and the amount of light available (57). Carbohydrate concentrations in needles show distinguishable variations and high correlations with age of foliage and with season, which serve to explain their resistance to damage in cold weather (29).

Hormone concentration has been found to be consistently higher in fast-growing than in slow-growing young ponderosa pine. In the slow-growing trees the leader always contained more auxin than the side shoots. It was concluded from these studies that higher concentration of the growth hormone (which parallels vigor) is a hereditary trait (92).

Ponderosa pine has the ability to develop abnormal leaves arising from the hypertrophy of the scales after certain types of injury. The characteristics of these atavistic leaves are interpreted as suggesting the possibility of remote ancestry (77). The recovery process subsequent to browsing injury on 7-year-old seedlings of the species has been described as "substitute budding" and "substitute growth" (32).

The average content of acetone-soluble extractives in ponderosa pine varies considerably between sapwood and heartwood, being within the limits of 2.0 to 9.8 percent for the former and 3.5 to 31.5 percent for the latter, of the dry weight of wood (5). Resin can constitute as much as 86.4 percent of the oven-dry weight of the wood after extraction, and the lower the stocking of the stand, the larger the tree crown, and the lower in the tree the sample is taken, the higher is the resin content of the wood (108).

The gum turpentine of ponderosa pine characteristically contains, with very few exceptions, large quantities of d-delta-3-carene mixed with pinenes (95). The former constituent was undiscovered when the earliest investigations on the subject were made (122). The ratio between the pinenes and the carene in different trees of ponderosa pine may vary, as shown by fluctuation of the optical properties in individual samples. In certain localities within its range, some trees of the species may provide dextro-rototary terpenes; others may provide levo-rototary terpenes. Furthermore, the different forms, races, and hybrids of the species can each have their own peculiar turpentines (94). In fact, this point can be used to determine the relationship of closely allied species (96). Gum turpentine from a ponderosa pine in northern Idaho contained about 1 to 2 percent dl-Alpha-pinene; 12 percent l-Beta-pinene; 5 percent Beta-myrcene; 64 percent d-delta^3-carene; 5 percent l-limonene; 2 percent menthyl chavicol, and 4 to 5 percent sesquiterpenes, part of which is cadinenelike sesquiterpene (62). Samples throughout its United States and Canadian range indicate that the yield of turpentine will vary from 15 to 26 percent (94).

RACES AND HYBRIDS

Although ponderosa pine includes a number of geographic races over its widespread range only one variety (*Pinus ponderosa* var. *arizonica*) is recognized (76). The so-called Rocky Mountain form (as contrasted to the Pacific Coast form and designated as *Pinus ponderosa scopulorum*) occurring east of the Continental Divide, in the Central Plateau of western Colorado, Utah, eastern Nevada, Arizona, and New Mexico is believed by some to be a true variety due to anatomical or morphological differences (66, 111). Other investigators consider these differences purely a result of environment and adaptation (76, 137).

It has been shown that, at least in the first 25 years of a tree's life, races of ponderosa pine grown from seed collected from five geographical zones delimited by annual precipitation, exhibit a recognizable number of characteristics such as number of needles in the fascicle, needle length, internal needle structure, and tree growth rate which are considered as being inheritable (152). A somewhat similar investigation, with the added feature of three altitudes of planting (963 feet, 2,730 feet, and 5,650 feet above sea level), instead of one, revealed, in general, the same results. After 12 years of growth, plants from seed collected at 1,500 to 3,500 feet above sea level grew most in each of three planting sites (97). Still other experiments with transplants from seed collected over a considerable part of the species range have emphasized the great variation in average height (8.9 to 14.5 feet) that can be expected 18 years after planting. If average heights of trees on the five different planting sites are considered, the variations in heights are even more pronounced (2.2 to 20.8 feet) (10, 100). Thus the wisdom of using correct seed sources should be obvious to those who expect desirable development of the species when trees grown from seed of a specific climate and physiographic zone are employed in regeneration in a different locality.

A number of successful hybrids have been produced by crossing ponderosa pine with other races and species including *Pinus montezumae*, *P. ponderosa scopulorum*, *P. ponderosa arizonica*, *P. washoensis*, *P. latifolia*, and *P. jeffreyi* (44, 116, 117, 153).

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FOREST INSECT CONDITIONS in the INTERMOUNTAIN & NORTHERN ROCKY MOUNTAIN STATES DURING 1957

INTERMOUNTAIN FOREST & RANGE EXPERIMENT STATION

REED W. BAILEY, DIRECTOR

FOREST SERVICE

U. S. DEPARTMENT OF AGRICULTURE

OGDEN, UTAH APRIL, 1958

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FOREST INSECT CONDITIONS
IN THE INTERMOUNTAIN AND NORTHERN ROCKY MOUNTAIN STATES
DURING 1957

By

Division of Forest Insect Research

INTERMOUNTAIN FOREST AND RANGE EXPERIMENT STATION
Forest Service
U. S. Department of Agriculture
Ogden, Utah
Reed W. Bailey, Director

FOREST INSECT CONDITIONS IN THE INTERMOUNTAIN AND NORTHERN ROCKY MOUNTAIN STATES DURING 1957

The annual forest insect survey in the Intermountain and northern Rocky Mountain States during 1957 was aided greatly by cooperation of personnel in other Federal and State land-managing agencies, forest industries, and interested private land owners. Entomologists of the Intermountain Forest Experiment Station collected and coordinated forest insect information within the area.

Aerial observation of forested areas again proved indispensable in the detection phases of the surveys. Ground surveys were performed where reports or aerial observations indicated a need for further examination. While it was impossible to survey all forested areas during 1957, improved coverage was possible through cooperative effort, and it is doubtful that any serious infestations escaped detection.

Numerous forest insect situations in the area covered by these surveys are serious or potentially serious. Defoliators of various kinds seem to be more common than for several years. The larch casebearer, a European species that has been known in the East for many years, now has been found in western larch. Damage from bark beetles still occurs at levels that require control action. The highlights of the 1957 surveys are presented.

BARK BEETLES

Damage from bark beetles is not extremely heavy in the northern Rocky Mountain States. The serious outbreak of Engelmann spruce beetle of the past few years in Montana and northern Idaho is now a problem of "hot spot" infestations in a few areas. In other parts of the station territory some outbreaks that have required control efforts during the past few years are still active. A tendency toward increasing activity of mountain pine beetle reported last year was again noted.

DOUGLAS-FIR BEETLE

Dendroctonus pseudotsugae Hopk.

The Douglas-fir beetle is at a low level in most areas, judging by aerial and ground surveys. The aerial surveys being based on faders reveal loss from attack the previous year. Ground surveys plus observations during research studies confirm the downward trend.

A few areas are exceptions. In the Yellowstone River canyon in Yellowstone National Park approximately 25 percent of the mature overstory trees on 1,000 acres has been killed by the beetle during the past 3 years. These trees had been heavily defoliated by the spruce budworm from 1953 through 1955.

A few areas of activity were noted on the Boise and Sawtooth National Forests in Idaho. In western Wyoming, eastern Idaho, and Utah the beetle has continued to show a downward trend except on the Dixie National Forest and adjoining land where heavy damage continues. The fir type occurs in patches and practically all stands are heavily infested. On many pockets 300 acres or larger, almost total kill has occurred.

ENGELMANN SPRUCE BEETLE

Dendroctonus engelmanni Hopk.

Remnants of the extensive epidemic of 1952-1956 in Montana and northern Idaho persist in some stands of pure spruce where logging is being conducted for control purposes. In most areas where stands composed of pure mature spruce have been logged for beetle control, infestation has died out. Continued logging reduces the severity of the outbreaks but "hot spot" centers have been noted, apparently maintained by chunks, cull logs, and tops shaded by residual trees. Also blowdown trees adjoining cutting areas contribute to the infestation. Continued effort in these areas will be required to prevent increased damage.

The outbreak of Engelmann spruce beetle on the Bridger National Forest in Wyoming discovered in 1955 is still aggressive. The program of logging and use of trap trees continues. Surveys this season revealed approximately 37,000 infested trees and stumps on 24,000 gross acres. As much as 33 percent of the spruce has been killed in parts of the infestation. The infestation has not spread to adjacent spruce areas.

BLACK HILLS BEETLE

Dendroctonus ponderosae Hopk.

The present outbreak of Black Hills beetle on the Dixie National Forest and Bryce Canyon National Park is now in its eighth year. By a combination of logging and chemical treatment, populations have been reduced in control areas. Unfortunately, conditions are such that epidemic centers continue to develop in new areas. This year for the first time a large stand of virgin ponderosa pine on the Escalante side of the forest shows "red tops" that indicate that epidemic conditions may be encountered.

The ponderosa forests in the area suffered from deficient rainfall for the 7 years prior to 1957. This year rainfall was well distributed throughout the season and in amounts that should break the drought condition. Early winter snows have been encouraging. It has been assumed that deficient rainfall has contributed to stand susceptibility. It is hoped that the increased rainfall will increase the stand vigor and help to stop this epidemic.

MOUNTAIN PINE BEETLE

Dendroctonus monticolae Hopk.

The Intermountain and northern Rocky Mountain States have extensive lodgepole stands that favor development of epidemics of mountain pine beetle. During 1956 the surveys showed a tendency toward a buildup of populations in parts of Utah, southern Idaho, and western Wyoming. The 1957 surveys substantiated the observation.

The greatest concentration of infested trees is on the Wasatch National Forest; it continues an infestation that has been present at fluctuating levels for the last 17 years. The adjoining Ashley National Forest contains several epidemic centers.

In the Grand Teton National Park and the adjoining Teton National Forest numerous centers of infestation were found. Several centers were treated chemically during 1956 but additional areas appeared this year. Two small infested areas were found on private land near the upper end of the Targhee National Forest.

Lodgepole pine killed by mountain pine beetle

The mountain pine beetle in lodgepole pine in the northern Rocky Mountain areas continues at relatively low level. Two small infestation centers are known in northern Idaho and one in Glacier National Park. Losses in western white pine on the Clearwater National Forest, while slightly higher than during 1956, are considered normal.

The mountain pine beetle is also active in a second-growth stand of ponderosa pine in the Crystal Bay area of Lake Tahoe, Nevada. This outbreak threatens highly valued recreational private land including summer home sites. A recent survey indicates that this infestation is continuing at about the same level as last year. The cumulative loss since 1950 is considerable.

The present situation indicates that special attention must be given to lodgepole stands in view of the epidemic tendencies noted.

WESTERN PINE BEETLE

Dendroctonus brevicomis Lec.

Activity of western pine beetle in ponderosa pine stands of the Intermountain station territory remains at a low level. Infested trees can be found in most pine stands but are widely scattered.

SOUTHWESTERN PINE BEETLE

Dendroctonus barberi Hopk.

The southwestern pine beetle continues to kill ponderosa pine on the heavily used recreational areas of Charleston Mountain near Las Vegas, Nevada. Constant maintenance type of control throughout the active season has been in progress for several years.

DEFOLIATORS

For the past few years the area has been plagued by outbreaks of various kinds of defoliators. This year was no exception and even produced a new record for the West with the discovery of an infestation of larch casebearer.

SPRUCE BUDWORM

Choristoneura fumiferana (Clem.)

The spruce budworm has been a serious pest in Montana and northern Idaho for nearly 10 years. Spray projects since 1953 have treated more than 2 million acres.

The 1957 aerial and ground surveys show approximately 2,846,000 acres of Douglas-fir still infested, 90 percent of which is in Montana with the remainder in one area in northern Idaho. Infestations in some areas were less intense, others at the same level, and of course some showed heavier defoliation than during 1956. Infestations that have been severe for the past few years are causing considerable damage, and in many areas the younger understory trees have been killed.

In southern Idaho spruce budworm infestations became quite noticeable and severe during 1952. Since 1955 slightly more than 2 million acres of fir have been sprayed. Aerial and ground surveys during 1957 revealed about 512,300 acres of infestation on five national forests. Much of this acreage consists of defoliation that has been noticeable for only 1 or 2 years. The rate of increase in defoliation is particularly rapid on the Salmon National Forest.

For the first time since aerial spraying of budworm started in the West, damaging populations of mites developed in some areas sprayed in 1956. More detail is presented in the section on mites.

BLACK-HEADED BUDWORM

Acleris variana (Fern.)

High endemic populations of the black-headed budworm are reported throughout many Douglas-fir stands in Montana in conjunction with spruce budworm populations. This is particularly noticeable east of the Continental Divide. Epidemic populations of black-headed budworm caused heavy defoliation in western hemlock stands in scattered locations in the Kootenai National Forest and in Glacier National Park in Montana and in the Kaniksu in Idaho. Aerial surveys showed that these scattered infestations total approximately 32,000 acres on which hemlock damage is readily visible. Ground surveys have also recorded active infestations in grand fir stands in the Pend Oreille River drainages near Newport, Washington. Damage, however, is hardly visible. Additional ground surveys in hemlock stands indicate that although damage was heavy in 1957, overwintering budworm populations are light. Some areas showed a drastic reduction in larval population prior to pupation. Additional surveys of this nature are being made. It is believed that the trend of this infestation is toward endemic conditions. The black-headed budworm also occurs with spruce budworm in southern Idaho.

LARCH INSECTS

In 1955 and 1956 considerable defoliation of western larch in Montana and northern Idaho was reported. It was known that several species were involved in the infestations. Surveys and observations during 1957 have helped to clarify the situation.

At the higher elevations it appears that the budmoth, *Zeiraphera griseana* (Hubner), is most common. Examination of felled trees revealed that the budmoth caused a reduction in leaf surface of at least 50 percent in 1957.

A larch looper, *Semiothisa sexmaculata* (Pack.), also was found to be a widespread defoliator, but there are no records of its presence prior to 1955. It was found in every larch stand examined but at lower elevations than stands infested by budmoth. Looper populations were relatively light and the injury was negligible.

Populations of the two-lined larch sawfly, Anoplonyx occidens Ross, and occasionally the western larch sawfly, A. laricivorus Roh. and Midd., have been observed with populations of the larch looper throughout the range of western larch in Montana and northern Idaho. Damage by the sawflies appears slight.

Hibernating larch casebearers

The larch casebearer, Coleophora laricella (Hbn.), a European insect widely distributed in the Eastern United States, was first noted in northern Idaho in 1957. No doubt it had been present for some time before its discovery. An infestation of approximately 15,000 acres near St. Maries was reported in young larch stands. The feeding produced severe defoliation on the infested trees, and a heavy population is now hibernating on twigs. When an introduced insect appears in a new area there is concern over its behavior and damage under new environmental conditions. Intensified surveys should be made to determine the full extent of its distribution.

DOUGLAS-FIR TUSSOCK MOTH

Hemerocampa pseudotsugata McD.

During 1951 the Douglas-fir tussock moth reached outbreak proportions in Owyhee County in Idaho. At that time about 10,000 acres of second-growth Douglas-fir were heavily infested. The following year the outbreak subsided, with limited tree mortality and some top killing. The fir is growing on an excellent site and the prospects are good for future timber production.

In 1956 the insect was again reported active in the same area. Surveys revealed considerable defoliation in parts of the infestation. There was evidence of considerable parasitism. During the present season defoliation again occurred ranging from light to heavy. In areas classified as heavy the greatest defoliation occurred in the upper crowns, and top-killing could result where tops were denuded. A gross area of 26,000 acres was mapped from the air. Unless control is attempted or biological factors operate at higher level, this infestation could produce considerable damage to the stand next year.

Douglas-fir tussock moth larva

Within the Owyhee area a confounding situation on alpine fir was encountered. Heavy defoliation was noted, but the insect causing it has not been identified. The type of damage present on the alpine fir with the absence of pupal cases has some characteristics of sawfly damage. (See alpine fir defoliator.)

ALPINE FIR DEFOLIATOR

For the second year heavy defoliation of alpine fir has occurred in Idaho in areas sprayed for budworm control the previous year. This year it was found outside sprayed areas. Approximately 153,000 acres are affected, 103,700 of which are on the Boise National Forest. Since the survey was based on damage, the insect was not available for collection and identification at the time survey crews were in the area. However, a few collections of insects made during research studies may include the defoliator but contents of the samples have not yet been identified.

FIR NEEDLE MINER

Epinotia meritana Hein.

The outbreak of fir needle miner in the Bryce Canyon National Park area in southern Utah is now reduced to endemic level. Partially responsible for the decrease was the aerial test spraying of about 4,000 acres with an oil solution of malathion. Parasites also contributed to the over-all reduction of the needle miner population. Infestations on adjoining Dixie National Forest land also show a significant downward trend.

Approximately 10,000 acres of white fir were heavily defoliated during the course of this epidemic in the Park and on the Forest. Some tree killing occurred, principally understory trees. The stand is now in a weakened condition and therefore more susceptible to fir engraver beetles, primarily Scolytus ventralis.

White fir defoliated
by needle miner

DOUGLAS-FIR SAWFLY

Neodiprion abietis complex

Surveys show that sawflies are still active in the Craters of the Moon National Monument in southern Idaho. The infestation is not especially serious, but the limited fir in the area has considerable aesthetic value. Sawflies in Douglas-fir have been observed at endemic levels rather generally throughout southern Idaho.

PINE BUTTERFLY

Neophasia menapia (F. & F.)

Following the control work on the Boise National Forest in Idaho a few years ago, special attention has been given to detection of any pine butterfly infestations. This year several localized infestations were discovered on the Payette, Boise, and Salmon Forests; none of them were of any size or consequence; but they indicate need for continued vigilance.

ENGRAVER BEETLES

ALPINE FIR ENGRAVER

Scolytus and/or *Dryocetes*

Losses from these beetles in southern Idaho are scattered throughout the fir areas generally at endemic levels. The only heavy concentration of damage is within the Roaring River drainage on the Boise Forest.

Generally in eastern Idaho, western Wyoming, and in Utah the damage caused by the fir engraver beetle (*Scolytus ventralis* Les.) seems to be decreasing, but many trees are being killed in widely scattered areas throughout the region.

In southern Utah in and near Bryce Canyon National Park fir engraver beetle activity has increased sharply in the white fir stands weakened by the fir needle miner (*Epinotia meritana* Hein.).

IPS ENGRAVER BEETLES

Losses in ponderosa and western white pine stands from engraver beetles were insignificant in 1957.

Increased activity by *Ips confusus* (Lec.) in areas in southern Utah and western Nevada have been noted on pinyon pine. In centers of infestation, groups as large as 3,000 trees have been killed.

SPRUCE MEALYBUG

Puto sp.

About 60,000 acres of Engelmann spruce in southern Utah in two centers on the Dixie and Fishlake National Forests are heavily infested with a mealybug. From present knowledge it occurs only in this spruce area. The mealybug infests all ages from reproduction to mature trees. Limited studies of the life history and habits are being conducted to develop basic information needed to assess its importance. Considerable damage, in the form of tree deformity and reduced vigor is present in areas where the pest has been active for several years. The extent of tree killing has not been determined but probably occurs only after continued feeding and gradual decline in vigor. No control methods are known.

Hibernating spruce mealybug
(greatly enlarged)

COOLEY GALL LOUSE

Chermes cooleyi Gill

High endemic infestations of the Cooley gall louse were reported in Douglas-fir Christmas tree stands in the upper Kootenai River and Tobacco River valleys in northwestern Montana. The infestations are associated with severe infections of the Douglas-fir needle blight, Rhabdocline pseudotsugae Syd. Dr. Waters of Montana State University visited the stands with entomologists and confirmed the presence and severity of the needle blight.

SCALE INSECTS

Small localized infestations of the black pine leaf scale, *Nuculaspis californica* (Coleman), and the pine leaf scale, *Phenocaspis pinifoliae* (Fitch), were reported on ponderosa pine trees near Spokane, Washington. These infestations are remnants of epidemic populations that were reduced in 1951 and 1955 by extremely low temperatures. Current damage is insignificant except on a few trees.

MITES

During this year a new situation developed. Spider mite damage, primarily by *Oligonychus ununguis* (Joc.) appeared in Montana and southern Idaho in fir stands sprayed during 1955 and 1956 to control budworm. A few lesser infestations have been noted outside spray areas, but heavy populations and damage coincide with previously sprayed areas. About 790,000 of 885,000 acres sprayed during 1956 in Montana show damage by mites. In southern Idaho some 22,300 acres have been damaged. Foliage that is heavily fed upon becomes yellowish and foliage and smaller twigs appear desiccated. The twigs in many cases are brittle.

It is believed that spraying in 1955 and 1956 coincided with a natural upsurge in mite populations resulting in greater damage in sprayed areas. There are numerous references in literature to increases of mite populations following use of DDT. Millions of acres have been sprayed since 1949 without mite problems. The life of an upsurge in mite populations in forests is not known but the few records available in western forests in nonsprayed areas indicate that outbreaks are generally short lived.

Entomologists from Canada who have had wide experience with mites visited areas in Montana. Information furnished by these specialists will be of great value in subsequent observations to assess the severity of the mite damage.

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INTERMOUNTAIN INFILTROMETER

by

PAUL E. PACKER

DIVISION OF WATERSHED MANAGEMENT RESEARCH

INTERMOUNTAIN FOREST & RANGE EXPERIMENT STATION
FOREST SERVICE
U. S. DEPARTMENT OF AGRICULTURE
OGDEN, UTAH
REED W. BAILEY, DIRECTOR

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INTERMOUNTAIN FILTROMETER

By
Paul E. Packer
Division of Watershed Management Research

INTRODUCTION

Numerous kinds of infiltrometers have been developed in recent years for obtaining information about the capacity of watershed lands to take in water at the soil surface. Some, such as the tube or closed ring type (1, 5, 6, 11),1/ provide information only on infiltration and percolation rates. Others have devices for collecting and measuring surface runoff and eroded soil (2, 3, 7, 9, 10, 12, 13). The latter are especially well adapted for studying storm runoff and erosion control problems in which rainfall impact is an important factor. For studying such problems on the watershed lands of the Intermountain region, experience has indicated that an infiltrometer should embody the following features:

1. Sufficient lightness in weight for easy portability by two men over steep topography.

2. Sufficient plot size to encompass a representative sample of the interspersed vegetation, litter, and bare soil commonly found on Intermountain range lands.

3. Provision for quickly making applicator nozzle adjustments to obtain uniform distribution of rainfall over the plot.

4. Provision for applying artificial rainfall at rates up to 6 inches per hour and for changing rainfall rates during a test when it is desired to simulate the variable rates normally expected during torrential rains.

An infiltrometer to meet these requirements was developed at the Intermountain Forest and Range Experiment Station in 1947, and has since been used at various locations in Idaho and Utah. This apparatus is herein described. Suggestions are included regarding its field installation, calibration and operation, and the laboratory procedures and related measurements that are usually involved. An itemization of all parts of each of the several units and estimates of the cost of each unit are also given as a guide for those who may wish to construct the apparatus.

1/ Numbers in parentheses refer to Literature Cited, page 40 .

DESCRIPTION

The Intermountain type-F infiltrometer is a portable set of apparatus for applying artificial rainfall at either constant or variable rates up to 6 inches per hour on a sloping area about 9 x 9 feet in size, and for collecting and measuring resultant surface runoff and eroded soil from three 2- x 6-foot plots within the wetted area. Infiltration rates can be determined from the difference between rates of applied rainfall and runoff. The apparatus consists of ten units.

Water Supply.--This unit conveys water from a supply source to storage tanks in the vicinity of test-plot sites. It consists of a rotary high-pressure pump, 1,500 feet of 1½-inch linen discharge hose, two aluminum storage tanks having a combined capacity of 1,000 gallons, and 800 feet of 3/4-inch plastic gravity hose. If test sites are more than about one-fourth mile from a stream, lake, or other source of water, the unit should include a 1,000-gallon tank mounted on a 1½-ton truck. If small or unclear streams are to be used as the water supply, the unit should also include a supply tank of about 300 gallons capacity, which can be installed in or adjacent to the stream as a reservoir and sediment trap.

Pressure Circulation.--This unit conveys water at equal and proper pressure from an operating reservoir to each nozzle of a rainfall applicator unit. Principal items of equipment are an aluminum or galvanized operating reservoir of about 10 gallons capacity; a high-pressure rotary pump equipped with about 20 feet of 1-inch high pressure rubber discharge hose; a cylindical aluminum pressure tank of about 30 gallons capacity equipped with a pressure gage, a control valve, a bypass valve, a relief valve, and 14 tank valves; fourteen 3/8-inch plastic discharge hoses connecting these tank valves to the rainfall applicator nozzles; and a 3/4-inch plastic bypass hose to return excess water from the pressure tank to the operating reservoir.

Plot.--This unit includes a watertight frame of fixed dimensions for inclosing three 2- x 6-foot plots, to which simulated rainfall is applied, and from which runoff water and sediment are discharged. It consists of six steel cutoff walls, each 6 x 72 inches in size; a runoff spillway assembly consisting of three separate spillways, each 2 feet wide and welded together in a unit that attaches to the lower plot cutoff wall; a spring steel plot wall driver slightly under 6 feet in length, which is slotted to fit over the plot walls and prevent battering their edges during installation; and either an 8- or a 12-pound sledge hammer for driving the cutoff walls into the ground.

Windbreaker Tent.--This unit is used to protect the rainfall applicator unit and plots from wind disturbance during tests, in order to facilitate obtaining a uniform rainfall pattern over the plots and rain gages. The main parts of this unit are a tubular aluminum framework of four extendable legs and eight connecting crosspieces, a lightweight canvas tent cover that fits over the frame, and eight mooring stakes and guy ropes.

Runoff and Sediment Collection.--This unit provides for obtaining periodic samples of water and sediment, as well as a total catch of all water and sediment discharged from plots during a test period. It consists of three collector troughs with lids, three sets of three 10-gallon milk cans with lids for catching total discharge, about 6 dozen quart jars with lids for collecting periodic samples of discharge, and a stopwatch graduated in seconds for timing sampling periods.

Rainfall Collection and Measurement.--This unit provides for obtaining a periodic and total measure of rainfall during an infiltrometer test period. It consists of two precision-made trough gages 6 feet long, 1.8 inches wide, and 3.0 inches deep that mount on the outside plot walls; two collector tubes--one from each gage--which are joined into a single tube that carried rainfall to a rainfall measuring can equipped with a staff gage.

Rainfall Applicator.--This unit provides a rigid and easily adjustable support for mounting the rainfall nozzles accurately in relation to the test plots to produce a uniform rainfall pattern of prescribed intensity. This unit consists of two adjustable nozzle racks of aluminum channel construction, two batteries of 7 F-type nozzles mounted on the racks with movable ball-and-socket fittings, and a precision-made nozzle adjusting level.

Runoff and Sediment Measurement.--This unit is used to separate runoff water and sediment discharged from the infiltrometer plots and to measure the amount of each. Equipment includes three sets of three 10-gallon milk cans; three sets of three galvanized filter funnels; filter papers; four lucite graduates of 100, 250, 500, and 1,000 cubic centimeters in size; a 200-pound capacity platform scale; a 2,000-gram capacity triple beam balance; and, if electrical power is available, a soil oven. This equipment is kept at a work center or field camp where the runoff water and sediment from total plot discharges and from samples can be separated and measured under cover.

Accessory Equipment.--This unit includes a tool kit, spare parts, and other items of equipment needed in the calibration, installation, and operation of the infiltrometer.

Transport.--This unit consists of either one 1½-ton capacity stakeside truck or two 3/4-ton capacity stakeside trucks for transporting the unit to the field. A second 1½-ton capacity truck, equipped with a 1,000-gallon water tank, may be needed where it is desired to test infiltrometer sites beyond feasible pumping distance.

FIELD INSTALLATION

Experience with the infiltrometer has shown the following sequence, with two men working as a team, to be the most efficient for setting up the apparatus for field operation.

Water Supply.--This unit should be installed first in order to provide a supply of water for cleaning other units before they are set up, and to make certain the test plot sites are within reach of a water supply source.

The pump should be installed on a plank base near the supply tank and leveled to avoid vibration and creep (fig. 1). The suction hose intake, equipped with a strainer, should be kept at least 6 inches off the tank or stream bottom to minimize chances of sediment entering the pump. The discharge hose to the storage tanks should be laid out as straight as possible to avoid turns, which create friction. On steep slopes, it is generally necessary to tie the discharge hose couplings to stakes to prevent the hose line from sliding downhill when full of water.

Figure 1.--Typical water development in small stream showing earthen dam, water supply pipes, open-top tank, suction hose, pump, and discharge hose.

The two water storage tanks can be rolled or carried by two men. They should be set on level ground above the areas to be tested (fig. 2). The tanks are joined by a Siamese coupling, which permits free flow of water between them and maintenance of a common water level in both when filling or draining.

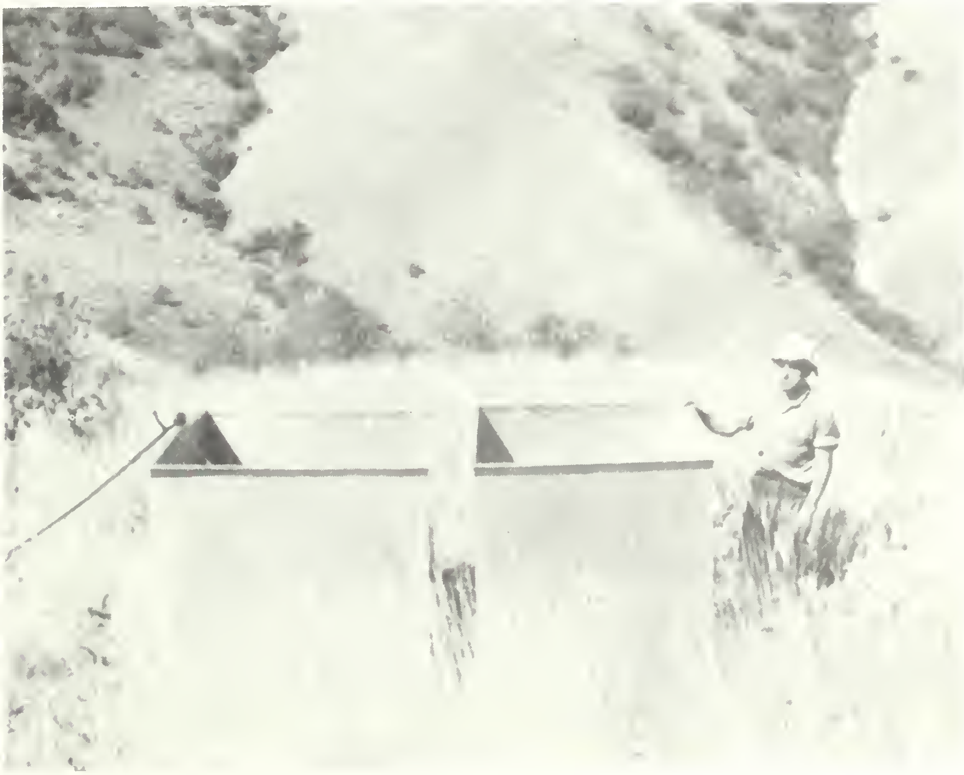

Figure 2.--Water storage tanks on ridge above stream source. In this instance water was pumped from the ravine in background over a 350-foot vertical lift to the tanks through 800 feet of $1\frac{1}{2}$-inch linen hose.

The gravity hose is then attached to the Siamese coupling and laid out down hill to the 10-gallon operating reservoir near the test plots. The flow of water through the gravity line is controlled at the storage tanks by a valve in the Siamese coupling and at the lower end of the hose by a gate valve (fig. 3).

Pressure Circulation.--As soon as water is available through the supply unit, the pressure circulation unit should be installed at the test site. The operating reservoir should be located about 20 feet from the proposed test plot. Though only 10 gallons in capacity, this small operating reservoir provides sufficient capacity, by using the gate valve on the gravity hose, to regulate inflow from the storage tanks at the same rate as consumption by the infiltrometer.

Figure 3.--Siamese coupling between storage tanks showing valve and plastic gravity hose.

The pump should be set up about 15 feet from the test plot on a level plank base. It may be found desirable to set the pump on a waterproof tarpaulin so as to divert exhaust water away from the base of the pump. The suction line from the pump, equipped with a strainer, is inserted in the operating reservoir. The pressure hose from the discharge side of the pump to the pressure control tank is connected by means of two quick snap-on couplings (fig. 4).

The pressure control tank should be located about 5 feet below and 5 feet to one side of the lower edge of the proposed test plot. A pressure gage is attached to the tank with a quick snap-on fitting. The bypass hose is coupled to a bypass valve on the tank and returned to the reservoir. This bypass line permits higher pressure in the line from the pump than is maintained in the tank and, hence, acts as a surge system to dampen pressure fluctuations in the tank. The pressure hoses from individual valves on the tank to the rainfall applicator nozzles are attached with quick snap-on couplings (fig. 5).

Figure 4.--Portion of pressure circulation unit showing the 10-gallon reservoir, suction hose, pump, and discharge hose.

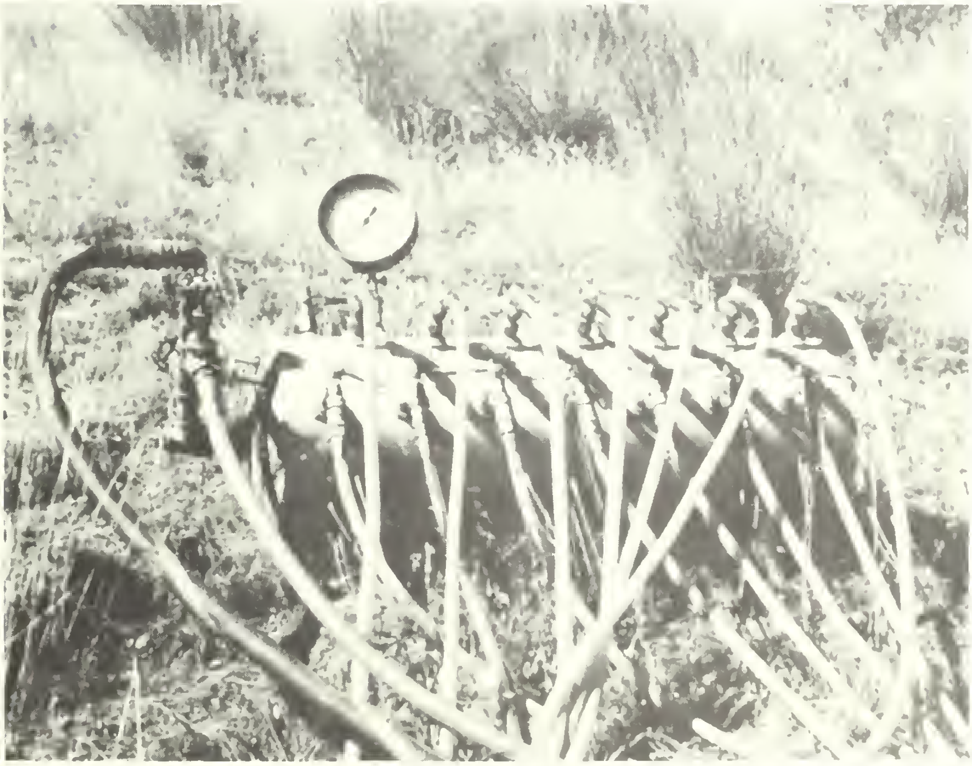

Figure 5.--Portion of pressure circulation unit showing pressure line from pump, pressure control valve, bypass valve, pressure control tank, relief valve, pressure gage, bypass hose, and 14 pressure lines to nozzles.

When this assembly has been completed, the pump can be started. However, before starting the pump, the bypass valve should be closed and the pressure control valve and top row of 7 tank valves opened. This permits escape of entrapped air in the tank as it fills. When the pressure tank is full, each nozzle pressure hose, in turn, should be thoroughly flushed out, being careful to insure that the pressure on the gage does not exceed 60 pounds per square inch.

Plot.--After determining the location of a test plot, the cutoff walls of the frame should be laid out on the ground in their relative positions just outside the plot boundaries (fig. 6). The lower cutoff wall is inserted first, one man holding the plot-wall driver on the wall, the other pounding it into place in the ground with a sledge hammer. As soon as the top edge of the cutoff wall is flush with the ground, the runoff sill is slipped over the wall and also tapped down carefully until it is flush with the ground. Next, the two outside walls are installed in the same manner as the lower wall, but for only half their depth or about 3 inches. The upper wall is then slipped into place with the

Figure 6.--Installing a plot unit on an annual weed site in Idaho. The plot-wall driver is being employed to protect the side wall in the background from damage by the sledge hammer.

split-plate corner frames fitting tightly over the upper ends of the side walls and is driven halfway into the ground. The two inside walls are fitted into the split-plate slots of the upper wall and over the flanges of the runoff sill and driven halfway into the ground.

After the plot frames are installed, about 2 inches of soil should be cleared out from under the lower side of the runoff spillways to permit fitting the runoff collector troughs in place (fig. 7).

Figure 7.--A plot spillway with soil cleared away to provide space for runoff collector trough. A portion of the collector trough on the adjacent plot can be seen at right.

It is desirable to have from four to six complete sets of plot frames. This will permit setting up several plots in advance of rainfall application; also, by moving only the rainfall applicator and tent, successive or repeated applications of water can be made without disturbing the test plots (fig. 8).

Figure 8.--Plot walls and runoff spillways installed on a triple plot. In this instance, the subplots were subjected to heavy, medium, and light artificial trampling disturbance.

Windbreaker Tent.--The tubular aluminum tent frames can be assembled most conveniently at a point just above the plots but not over them. The frame should be assembled with the legs telescoped to give minimum height of about 6 feet. In this position, all brackets can be reached and the wingnut fasteners tightened by hand.

The tent cover can then be worked on over the top of the assembled frame from the uphill side and oriented so the reinforced canvas corners fit the frame corners properly. The slit front of the cover, equipped with either a zipper or snaps for closing, should be open for this fitting.

The four extension legs are then extended to their full length of about 9 feet and locked in that position by tightening a lock wingnut. Canvas ties on the inside corners of the cover are tied to the legs about halfway up to reduce wind slap. In the extended position, two men can easily move the tent downhill to a position over the plots by grasping a lower horizontal crosspiece on each side. The tent is then positioned over the plots so that each side is equidistant from the plot side walls--about $2\frac{1}{2}$ feet--and so the slit-front side of the tent is about 1 foot downhill from the runoff sill at ground level (fig. 9). The guy ropes are then fastened snugly to aluminum stakes driven about 8 or 10 feet out from the corners and sides.

Figure 9--Demonstration setup of infiltrometer showing tent framework and cover. During normal tests, the cover is lowered for protection against wind disturbance.

The tent should be left moored in the lower position with the slit front and side windows closed when unattended to reduce chances of wind damage. The tent can be moved without taking it down, though this procedure is recommended only when test plots are within 100 feet or so from one another.

Runoff and Sediment Collection.--The runoff and sediment collection unit should be installed after the windbreaker tent is in place over the plots. Each of the three collector troughs has a lip on the straight upper edge. This lip fits under the runoff sill and the collector trough lid fits over both the trough and sill so its upper edge comes to the lower edge of the plot. A sliding extension on the upper edge of the lid permits this relationship between the upper edge of the lid and the lower boundary of the plot to be maintained regardless of slope steepness (fig. 10).

Figure 10.--Runoff collector troughs installed on spillways of plots showing extension on lids and collector cans below.

Three pits should be dug just below the collector trough spouts to accommodate the collector cans. These collector cans should be set so the aluminum collars on the trough spouts are outside of the can. This permits rainfall drip on the trough lids to drain off before reaching the collector cans.

Rainfall Collection and Measurement.--The trough rain gages should be hung on each of the outside plot walls by metal brackets (fig. 11). The gage position should be adjusted so the lower end of each is opposite the lower edge of the plots (fig. 7).

The collector tubes are then screwed onto the threaded fittings at the lower end of each gage and the other ends of the tubes are joined into a single tube that is inserted into the stilling well of a calibrated rainfall measuring can. The rainfall measuring can is leveled by setting the two bubbles of the nozzle adjusting level to zero, placing this instrument in the bottom of the can and adjusting the can to center the bubbles. With the can leveled, a porcelain staff gage, graduated in hundredths of a foot, is inserted into a bracket on the inside wall of the can (fig. 12).

Figure 11.--Trough rain gages showing metal brackets for attaching gages to plot walls.

Figure 12.--Rainfall measuring can showing collector tubes from gages and porcelain staff gage.

Rainfall Applicator.--The rainfall applicator unit is best assembled just below the rainfall collector can, then moved directly uphill through the slit-front opening of the tent cover, and into place over the plot. Assembly is accomplished by folding the legs out from the nozzle racks and joining the ends of the racks with spread bars fastened with wingnuts to form a rigid frame. The frame is then positioned over the plot so that:

1. The center lines of the nozzle racks are 18 inches outside of the nearest side plot wall.

2. The end nozzles on each rack are opposite the upper and lower plot walls, respectively.

3. The nozzle mouths are 30 inches above the plot surface. The pressure hoses from the circulation system are then fastened to the nozzle mounts under the racks. With the nozzles pointed away from the plots by swiveling them on their ball-and-socket bases, the circulation system is started and each nozzle flushed to insure that none is clogged. The nozzles are then set with the nozzle adjusting level, each at the proper angle as determined during calibration (fig. 13).

When the nozzles have been adjusted, the collector troughs, rain gages, and rainfall collector tubes should be flushed with water to prewet them and insure they are clean. The front of the tent cover should then be closed. The infiltrometer is then ready for operation.

Complete installation, as outlined, normally requires about 3 hours' work by two men after the water supply unit is in. It is desirable to locate as many test sites as possible within gravity line reach of the water supply storage tanks, in order to avoid moving the water supply unit more often than necessary. When operations permit testing of sites in close proximity, much of the equipment assembly can be moved intact. Under such conditions, changing from one site to another requires about 2 hours.

Figure 13.--One of the applicator nozzle racks showing hoses from pressure tank, flexible nozzle bases, type-F nozzles, and nozzle adjusting level. When setting the nozzle it is important to grasp the nozzle and not the level.

CALIBRATION

The infiltrometer must be calibrated prior to field use. This is necessary to determine the following relationships:

1. The angular setting of the nozzles in relation to the test plots to obtain uniform rainfall distribution over the plots.

2. The ratio of rainfall on the plots to rainfall on the trough gages.

3. The rainfall depth relationship between the trough gages and the rainfall collector can.

Calibration can be accomplished satisfactorily either indoors or outdoors. However, where facilities such as a concrete floor and drain are available, indoor calibration is generally simpler. For outdoor calibration, the windbreaker tent should be used.

Determining Angular Setting of Nozzles.--The first calibration procedure is to determine the proper setting of each nozzle to obtain uniform rainfall distribution at each rainfall rate. The process is one of trial and error and consists of the following steps:

1. Establish a network of 32 small rain gages (No. 2 tin cans are satisfactory) uniformly distributed eight to each subplot and four along the outer edge of each rain trough. Lay burlap or canvas on the plots to minimize splash into rain cans.

2. Set nozzles at a trial angle and record angle of each.

3. Make three 10-minute rainfall applications at 35 pounds water pressure. After each 10-minute application, measure and record volume of catch in each can. Compute and record rainfall rate for each can. If calibration is performed on a slope, the computed rates should be corrected for slope before being recorded. Determine and record the average rate of the three rainfall catches in each can; also of all cans. Determine the maximum average can variation from the average of all cans. This deviation should not exceed 10 percent.

4. Repeat the three 10-minute rainfall applications as described under 2 and 3 above, until a combination of nozzle angle settings is found that produces a rainfall pattern within the desired limits of variation.

The manner in which the calibration may be recorded and handled to determine pattern uniformity is shown in a sample Infiltrometer Calibration Test Form (fig. 14).

When a rainfall pattern of desired intensity and uniformity has been obtained, a record of the nozzle numbers, their angular settings, and the position they occupy on the nozzle racks should be made and carried in an appropriate notebook for field reference. Matching reference lines should also be etched on the nozzle base and the nozzle rack, to permit orienting the nozzle in the same position each time before it is leveled.

Determining Plot-Trough Gage Rainfall Ratio.--It is essential to know the precise relationship between the amount of rain falling on the plots and that falling on the troughs lying just outside the plots on either side. This relationship can be established from test runs by determining the ratio of the average rainfall rate in the plot gages to that in the trough gages. This ratio is called the trough gage correction factor. A sample computation is shown on the sample Infiltrometer Calibration Test Form.

INFILTROMETER CALIBRATION TEST RECORD

ate 6/24/51 Test No. 7 No. Runs 3 Time per run 10 min

lope 45 % 24° 14' ° Slope Correction Factor (secant of slope angle) 1.10

onversion Factors:

plot gage rainfall rate (in./hr.) = test vol. (cc) X $\dfrac{\dfrac{60}{\text{test time (min.)}}}{\text{cc/in.}^3 \text{ X area of gage (in.}^2)}$ = .05179

trough gage rainfall (in./hr.) = test vol.(cc) X $\dfrac{\dfrac{60}{\text{test time (min.)}}}{\text{cc/in.}^3 \text{ X area of gage (in.}^2)}$ = .00141

ozzles: Left bank: No. 1-2-4-6-7 Right bank: No. 1-2-4-6-7
Angle 1° 3° 5° 3° 1° Angle 1° 3° 5° 3° -1°

Test Rain Volume (cc) — Plot Gages | Rainfall Intensity (in/hr) (corrected for slope) — Plot Gages

								Run No.								
5	1	2	9	10	17	18	29		25	1	2	9	10	17	18	29
5	66	67	71	73	70	68	67	1	3.70	3.76	3.82	4.04	4.16	3.99	3.87	3.82
7	68	67	70	72	71	69	69	2	3.82	3.87	3.82	3.99	4.10	4.04	3.93	3.93
6	66	64	68	71	72	70	71	3	3.76	3.76	3.65	3.87	4.04	4.10	3.99	4.04
								Av.	3.76	3.80	3.76	3.96	4.10	4.04	3.93	3.93
6	3	4	11	12	19	20	30		26	3	4	11	12	19	20	30
9	70	72	73	71	68	67	65	1	3.93	3.99	4.10	4.16	4.04	3.87	3.82	3.70
1	71	73	74	72	69	67	66	2	4.04	4.04	4.16	4.22	4.10	3.93	3.82	3.76
0	72	74	75	73	70	68	67	3	3.99	4.10	4.22	4.27	4.16	3.99	3.87	3.82
								Av.	3.99	4.04	4.16	4.22	4.10	3.93	3.83	3.76
7	5	6	13	14	21	22	31		27	5	6	13	14	21	22	31
4	67	70	70	72	74	75	74	1	3.65	3.82	3.99	3.99	4.10	4.22	4 27	4.22
5	66	69	70	71	73	74	73	2	3.70	3.76	3.93	3.99	4.04	4.16	4.22	4 16
4	64	66	68	71	72	73	71	3	3.65	3.65	3.76	3.87	4.04	4.10	4.16	4.04
								Av.	3.66	3.74	3.89	3.95	4.06	4.16	4.22	4.14
8	7	8	15	16	23	24	32		28	7	8	15	16	23	24	32
3	65	66	69	70	72	73	72	1	3.59	3.70	3.76	3.93	3.99	4.10	4.16	4.10
4	64	65	68	70	73	73	72	2	3.65	3.65	3.70	3.87	3.99	4.16	4.16	4.10
2	64	67	69	71	74	72	72	3	3.53	3.65	3.82	3.93	4.04	4.22	4.10	4.10
								Av.	3.59	3.66	3.76	3.91	4.00	4.16	4.14	4 10

Trough Gages (cc)	Run No.	Trough Gages (in/hr)
2560	1	3.97
2550	2	3.96
2545	3	3.95
2552	Av.	3.96

$\dfrac{\text{aximum variation from average of all gages (in./hr.)}}{\text{verage rainfall rate of all plot gages (in./hr.)}} = \dfrac{.36}{3.95}$ = 9.1% variation in rainfall over plots

$\dfrac{\text{verage rainfall rate of all plot gages (in./hr.)}}{\text{verage rainfall rate on trough gages (in./hr.)}} = \dfrac{3.95}{3.96} = .9974$ = trough gage correction factor

Figure 14.--Sample of infiltrometer calibration test record form.

The rainfall measured in the trough gages is multiplied by the correction factor to obtain plot rainfall. Ideally, this correction factor should be 1.0. If this factor varies from 1.0 to more than 5 percent, the distribution of rainfall over the plot should be rechecked and the distribution improved so as to bring the correction factor within 5 percent.

Determining Trough Gage --Collector Can Rainfall Relation.--To facilitate rapid determination of total rainfall in the trough gages at any time during a test, it is desirable to calibrate the rainfall collector can with reference to the trough gages. Knowing the intercepting area of the trough gages and the cross-sectional area of the collector can, this calibration is accomplished by relating a volume of water equivalent to a given depth on the trough gages to the depth created by this volume on a staff gage in the collector can. This process is repeated with successive increments of volume until the can is full, recording the depth each added increment creates on the staff gage.

The staff gage readings and trough gage depths are used to plot a curve from which trough gage depths for each 0.01 foot of staff gage depth can be read. These readings of trough gage depth are tabularized into a calibration table which should be carried in a field tatum or notebook.

It is recommended that a collector can 11.73 inches in diameter be used with trough gages having an interception area of 259.2 square inches. This provides an interval of 0.02 foot in the staff gage for every 0.1 inch of rainfall in the trough gages.

FIELD OPERATION

With the infiltrometer calibrated and installed on a plot site, a test may be begun when a supply of water sufficient for the duration of test desired has been accumulated in the storage tanks. This infiltrometer has been found to consume about 2.5 gallons of water per minute per inch of rainfall applied (table 1). The rate of consumption could be reduced substantially by remodeling the exhaust-cooling system of the pump so as to vent coolant water back into the reservoir (3) instead of wasting it out the exhaust.

Table 1.--Gallons of water required for infiltrometer tests of various rainfall durations and rates

Test time (minutes)	Rainfall rates					
	1	2	3	4	5	6
	Inches/hour					
10	25	50	75	100	125	150
20	50	100	150	200	250	300
30	75	150	225	300	375	450
60	150	300	450	600	750	900

A regular test run involves four operating procedures: (1) adjusting the pressure system; (2) measuring rainfall; (3) observing the plot surfaces; and (4) sampling and collecting runoff and sediment. It has been found convenient to have one operator devote his attention to the first two activities and, in addition, keep a record of rainfall and of elapsed time of the test, and to have a second operator handle the latter two activities and record duration of sampling periods.

Adjusting the Pressure System.--The pump is started after the bypass and pressure control valves are opened and all nozzle valves on the pressure tank are closed. As soon as the pump is running smoothly, the pressure gage should be brought to about 45 pounds pressure by adjusting the bypass and pressure control valves. At time zero--preferably at the beginning of an even minute--the valves to those nozzles to be employed are opened quickly and the pressure readjusted to 35 pounds. The gate valve on the gravity feed line is then quickly opened and adjusted to maintain a constant level in the 10-gallon operating reservoir.

After these initial adjustments, any pressure differential from 35 pounds can quickly be corrected with the pressure control valve. Numerous tests have been made without having to adjust pressure after the initial setting.

At the end of the test, the nozzle valves are quickly closed and the pump and gravity-feed gate valve turned off. The gravity feed line may be shut off about 40 seconds to a minute before termination of the test so the operating reservoir is nearly drained by the time the test ends.

Measuring Rainfall.--The rainfall rate is determined by measuring the depth of rain water on the staff gage in the rain collector can at periodic intervals, preferably every 5 minutes. The staff-gage reading in hundredths of a foot is recorded on an appropriate Infiltrometer Field Test Record Form (fig. 15). The difference between successive staff-gage readings is entered in the rainfall collector can calibration table

Study Title ______________________ Plot No. 76

INFILTROMETER FIELD TEST RECORD

Date 9/10/51

TIME		PRECIPITATION				SAMPLE DISCHARGE					TOTAL DISCHARGE						
		Depth			Inter-val rate				Rate		Weight					Water	
Elapsed	Interval	Staff gage	Interval amount			Time	Water volume	Soil weight	Run-off	Ero-sion	Discharge plus can	Can	Discharge	Soil	Water	Volume	De
(min)	(min)	(ft)	(ft)	(in)	(in./hr)	(sec)	(cc)	(gms)	(in./hr)	(lb/A/hr)	(lbs)	(lbs)	(lbs)	(lbs)	(lbs)	(in.³)	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	
Uncorrected for slope																	
0		0.00	–	–	–	–	–	–	–	–							
5	5	0.04	.04	.2	2.40	–	–	–	–	–							
10	5	0.10	.06	.3	3.60	10	4	.1	.0510	285.6							
15	5	0.16	06	.3	3.60	10	11	.2	.1400	571.2							
20	5	0.22	.06	.3	3.60	10	20	.3	.2540	858.0							
25	5	0.28	.06	.3	3.60	10	30	.4	3820	1143.6							
30	5	0.34	.06	.3	3.60	10	35	.6	.4450	1714.8							
31	1	0.36	.02	.1	1.20												
Average or total				1.80	3.60				.2120	762.2	29.75	23.25	6.50	.1036	6.40	177.1	.5
Corrected for slope																	
0		0.0	–	–	–	–	–	–	–	–							
5	5	.044	.044	.22	2.64	–	–	–	–	–							
10	5	.110	.066	.33	3.96	10	4.4	.11	.056	314.2							
15	5	.176	.066	.33	3.96	10	12.1	.22	.154	628.3							
20	5	242	.066	.33	3.96	10	22.0	.33	.279	943.8							
25	5	.308	.066	.33	3.96	10	33.0	.44	.420	1258.0							
30	5	.374	066	.33	3.96	10	38.5	.66	.490	1886.3							
31	1	396	.022	.11	1.32												
Average or total				1.98	3.96				.2332	838.4				.1140			.

Time rainfall began ______ 0

Time rainfall ended ______ 0 + 30'

Time overland flow began ______ 0 + 2'

Time overland flow ended ______ 0 + 30'

Time runoff began ______ 0 + 5

Time runoff ended ______ 0 + 31'

Total depth of water runoff (in.) .1128 / Total depth of rainfall (in.) 1.98 = 5.70 %r

Total soil weight (lbs.) .1140 X 3,630 = 414.0 lbs./acre er

Slope

Percent 45

Degree 24°14'

Correction factor 1.10

Remarks ______________________

Figure 15.--Sample of infiltrometer field test record form.

to determine inches depth of rainfall on the trough gages during the preceding 5-minute period. This depth is converted to rate in inches per hour, and both the depth and rate are recorded on the data form. Total rainfall at any time during a test is obtained merely by entering the staff-gage reading at that time in the calibration table.

Observing the Plots.--Observing what is taking place on the plots during a test is one of the most important activities. Each nozzle, when turned on, should be visually checked to see if it is clogged. If clogged, the operator manning the pressure system is notified and all nozzles are turned off until the stoppage is cleared and the nozzle reset. Whether a test should be resumed on the same plot following correction of a stoppage will depend upon the importance of plot wetness as a variable in the study.

The operator should watch the plots for the beginning and ending of depression storage, overland flow, soil movement, and runoff over the plot spillways. The time of these occurrences should be recorded on the Field Form. Such irregularities as leakage under plot cutoff walls, down rodent holes, etc., should also be recorded. It may also be desirable to make other observations. Among these, may be a record of the number and depth of rills or gullies, the depth of rainfall penetration under plants and litter and under bare soil, and changes in the surface features of the plot, such as development of erosion pavement, litter dams, etc. These items can be recorded on the back of the Field Form.

Sampling and Collecting Runoff and Erosion.--Different procedures should be used for collecting the plot discharge, depending upon the purpose of the test. When the objective is to determine the total amount of runoff and sediment produced by a given test rainstorm, the procedure simply involves catching all of the plot discharge in one or more collector cans for subsequent weighing and filtering. When the objective is to determine rates of runoff, sediment production, and infiltration, it is necessary to obtain rates of discharge during the test run.

A sampling procedure is recommended for the latter purpose in which 10-second samples of the discharge are caught in small jars at 5-minute intervals during the run. As each sample is obtained, it is capped and numbered and the sampling time, recorded by stopwatch, entered on the Field Form. The length of the sampling time and the sampling interval can be varied as conditions warrant. For example, shorter time samples at more frequent intervals are usually necessary for determining the slope of the depletion runoff after rainfall has stopped.

When information is desired about the infiltration capacity of a site, rainfall should be applied at a constant rate that is at least 1 inch per hour greater than the maximum rate of runoff. Infiltration values can be obtained from tests made on dry plots. However, it is generally desirable to obtain such data from plots that have been prewet.

The samples and/or total discharges collected from the field tests should be transported to a work center or field camp for separation and measurement of runoff water and sediment (fig. 16). Where a power supply is available, the samples can be handled by evaporating the water in a soil oven. Separation of total runoff from sediment is best accomplished by filtering.

Figure 16.--Weighing cans, filter funnels, and platform scales for handling total discharge measurements and triple-beam balance for weighing discharge rate samples.

Samples.--When samples are involved, they should be weighed to the nearest tenth of a gram, filtered, and the sediment air-dried for 48 hours. The sediment is then weighed and the volume of water in cubic centimeters determined by subtracting sediment weight from total sample weight. Both the volume of water and the weight of sediment are recorded opposite the proper sample period on the Field Test Form. Each is then extended from the sampling time to computed amounts discharged during the 5-minute period in which they were taken and converted, respectively, to runoff in inches per hour and erosion in pounds per acre per hour. These values are recorded on the Field Form under "Sample discharge rate" and are used to compute an average runoff and erosion rate during the test period.

The infiltration rate for each 5-minute period is obtained by subtracting the runoff rate from the rainfall rate for each corresponding period.

Total Plot Discharge.--When total plot discharges have been collected, the numbered can containing water and sediment are weighed to the nearest quarter of a pound to obtain total discharge weights. The discharge is filtered and the sediment air-dried for 48 hours. The sediment is weighed in grams, converted to pounds, and the weight subtracted from total weight of discharge to obtain weight of runoff water. The pound values of both are recorded on the Field Form under "Total discharge." The weight of water is converted to volume and then to inches depth over the plot.

All values recorded on the Field Form, including precipitation depth and rate, sample runoff and erosion amounts, and total runoff and erosion are corrected for variation in slope gradient. This can be done by multiplying each value by an appropriate slope correction factor. This correction factor, the secant of the slope angle, reduces all measurements to a common horizontal base. The corrected values are recorded in the appropriate columns on the lower half of the Field Form.

The data given on the sample Field Form were obtained from a plot on which runoff and erosion were measured both by sample and total yield procedures. The percent of runoff and pounds per acre of erosion shown in the lower right hand corner of the form were computed from total yield measurements. They show that runoff was 0.1128 inch or 5.70 percent of the rainfall during the 30-minute test period, and 0.1140 pound of soil or 414.0 pounds per acre were eroded from the plot.

The sample data show that the average runoff rate was 0.2332 inch per hour or 0.1166 inch during the 30-minute test. This amount is equivalent to 5.89 percent runoff or very nearly the same as the total runoff yield actually obtained. The sample data also show that the average rate of soil erosion was 838.4 pounds per acre per hour or 419.2 pounds per acre during the test, which was nearly the same as the total erosion obtained. Frequent similar checks of amounts of runoff and erosion obtained both by sampling and total catch indicate that, with carefully collected and accurately timed samples, the error involved in sampling can generally be held within about 5 percent.

RELATED MEASUREMENTS

Measurements of runoff and sediment production from infiltrometer plots are not especially meaningful unless they can be related to the site characteristics that account for them. These may include subsurface features such as soil pore space (4), bulk density, texture, structure, depth, organic matter, activities of soil organisms, and previous moisture condition. They may also include such surface characteristics as the kind and amount of plant cover (7), litter, size and dispersion of bare soil openings, erosion pavement, slope steepness, and surface disturbances such as trampling by livestock (8).

Inclusion of such site characteristics or treatments may be one of the most important phases of an infiltrometer study. Observations and measurements of surface characteristics usually should be made immediately following installation of the plot unit. At that time, there is no other equipment in place over the plots to impede movements necessary to obtain the desired measurements. Measurements of below-surface characteristics should be delayed until after the test has been completed to avoid the disturbance involved in obtaining them.

CONSTRUCTION SPECIFICATIONS

The Intermountain infiltrometer is not available commercially. It must be custom made. Because of the large number of items made from extruded and sheet aluminum, it is advisable to have the work done by someone familiar with working and welding aluminum. To assist in procurement and assembly of an infiltrometer, all parts with specifications and approximate costs are listed by major units.

Water Supply Unit

Water Development

Two pipes, 8' x 1½" of 1/8" or heavier gage aluminum

One tank, 42" long, 30" wide, 30" deep, of 1/8" aluminum sheet, welded seams, 1" flanged top edges, steel handles each end

If needed for hauling water, one tank, standard round type, 4'6" x 8' capacity 1,000 gals.

Pumping

One pipe strainer, 1½" female threaded, free-flow, Fisher 260 or equal

One suction hose, 6' x $1\frac{1}{2}$", wire reinforced, brass couplings for spanner wrench $1\frac{1}{2}$" male and female

One pump, gasoline-powered, rotary type, brass $1\frac{1}{2}$" male suction and discharge fittings. Recommend pump equal to or better than Pacific Marine Type "Y" or "NY" pumpers. The suitability of various kinds of pumps for infiltrometer work is discussed in some detail by Dortignac (6).

Linen firehose, $1\frac{1}{2}$" in 50' lengths with $1\frac{1}{2}$" brass couplings, mfg.-tested to withstand 300 lbs. square inch pressure. Recommend up to 1,500 feet in rough, dry terrain.

Water Storage

One tank, 60" long, 47" wide, 48" deep, of 1/8" aluminum sheet, welded seams, 1" flanged top edges, steel handles each end, capacity approx. 600 gals.

One tank, 54" long, 36" wide, 48" deep, of 1/8" aluminum sheet, welded seams, 1" flanged top edges, steel handles each end, capacity approx. 400 gals.

Two outlets, $1\frac{1}{2}$" female threaded of steel, welded one to each of above tanks near bottom adjacent corners (see fig. 3).

Siamese Coupling

Two bushings, $1\frac{1}{2}$" male to 3/4" female, steel.

Two 90° street elbows, 3/4" galvanized.

Two close nipples, 6" x 3/4", galvanized.

One union, 3/4", galvanized.

One tee, 3/4", galvanized.

One barrel valve, 3/4" male pipe-threaded inlet, 3/4" male hose threaded outlet, brass.

Gravity Feed

Plastic hose, 3/4" in 100' lengths, 3/4" brass couplings, mfg.-tested to withstand 225 lbs. square inch pressure. Recommend up to 800 feet to provide latitude in operations.

One bushing, 3/4" female hose threaded to 1" male pipe threaded, brass.

One valve, 1" gage type, brass.

Estimated total cost of water supply unit: $1,330.

Pressure Circulation Unit

Operating Reservoir

One milk can, 10-gallon size, galvanized.

Pumping

One pipe strainer, 1½" female threaded, free-flow, Fisher 260 or equal.

One suction hose, 6" x 1½", wire reinforced, brass couplings for spanner wrench, 1½" male and female.

One pump, gasoline-powered, rotary-type, brass 1½" male suction and discharge fittings. Recommend pump equal to or better than Pacific Marine Type "Y" or "NY" pumpers.

Two tarpaulins, 10' x 10', canvas waterproofed.

One reducer, 1½" to 1", female pipe threaded, galvanized.

Two couplings, 1" brass, quick snap-on type, 1" male pipe threaded one end, 1" female hose threaded one end.

Rubber industrial hose, 15' x 1", 1" male hose threaded brass fittings both ends.

Pressure Control

Two valves, 1" gate type, brass.

One 90^{o} street elbow, 1" galvanized.

Two close nipples, 2" x 1", galvanized.

Two tees, 1" galvanized.

One plug, 1" male threaded, brass.

One bushing, 1" female to $1\frac{1}{2}$" male, brass.

Pressure Tank and Accessories

One tank, pressure type, 30" long x 14" diameter, of 1/4" of heavier gage aluminum plate, double welded seams, equipped with sixteen 3/4" pipe threaded female fittings double welded, one $1\frac{1}{2}$" pipe threaded female fitting in one end, four 8" legs of $1\frac{1}{2}$" aluminum alloy tubing, and two steel handles. Should pressure test at 120 lbs. square inch pressure (see fig. 5).

One valve, pressure relief type, 3/4" brass, adjustable from zero to 100 lbs. square inch pressure.

One bushing, 3/4" male to 1/4" female, pipe threaded, steel.

Fourteen barrel valves, 3/4" brass, male pipe threaded inlet, male hose threaded outlet.

One bushing, 1" male pipe threaded to 3/4" female hose threaded, steel.

One pressure gage, brass railroad locomotive type, reading from zero to 70 lbs. square inch pressure, with 1/4" globe valve stem.

One coupling, brass, quick snap-on type, 1/4" male threaded one end, 1/4" female threaded one end.

Fifteen couplings, brass, quick snap-on type, 3/4" male hose threaded one end, 3/4" female hose threaded one end.

Fifteen plastic hoses, 25' x 5/8", with 3/4" brass hose fittings.

Estimated total cost of pressure circulation unit: $810.

Nozzle Rack

Two channels, 8' long, 4" wide, 2" deep, of 1/4" or heavier gage aluminum plate; tapped for 3/4" pipe threaded bushings at 1-,2-,3-,4-,5-,6-, and 7-foot marks along center line; tapped for 1/4" screws 1/2" from each end on center line; fitted with 1/4" aluminum plate leg supports 4-1/2" x 8" centered on bottom of channel 6" from each end and welded in place (fig. 17).

Figure 17.--Detail of rainfall applicator nozzle rack showing bushings for nozzles, tap and wing-nut for spreader bar, and leg assembly.

Two spreader bars, 9'4" x 1" x 1" angle aluminum alloy with 3/4" milled slots at right angles to length 2" from each end to receive 1/4" screws on ends of channels, equipped with corner braces 20" x 1" x 1/8" galvanized strap iron hinged 12" from ends of spreader bars with 1/4" screws and slotted on other ends at right angles to length of braces.

Fourteen bushings, aluminum alloy, 3/4" pipe threaded, seven to each channel screwed into taps.

Fourteen couplings, brass, 3/4" female pipe threaded to 3/4" female hose threaded.

Fourteen couplings, brass, 3/4" quick snap-on type, hose threaded.

Fourteen shower heads, brass, 3/4" ball-and-socket type, pipe threaded.

Fourteen type-F nozzles, details of construction and specifications shown in Figures 18 and 19.

Nozzle Adjuster

One nozzle adjusting level, 5" x 4" of 1/4" blued brass stock with milled nozzle mount beneath level base to fit over 1" diameter nozzle ends; equipped with two adjustable 15-minute bubble levels mounted at right angles, one fixed, the other hinged and adjustable over 17-degree quadrant, locking with set screw. This is a custom-made instrument (see fig. 13).

Sliding Leg

Four sliding legs, of fitted 2" and 1-7/8" aluminum alloy tubing of 1/8" gage, adjustable from 20" to 30" length and locked by 1/4" friction screw and wingnut; equipped with 8" diameter aluminum mud plate of 1/8" gage and 1-7/8" pointed steel spike welded into bottom of leg; equipped with double extruded hinge mount of 1/4" aluminum plate tapped for 1/4" hinge bolt (see fig. 15).

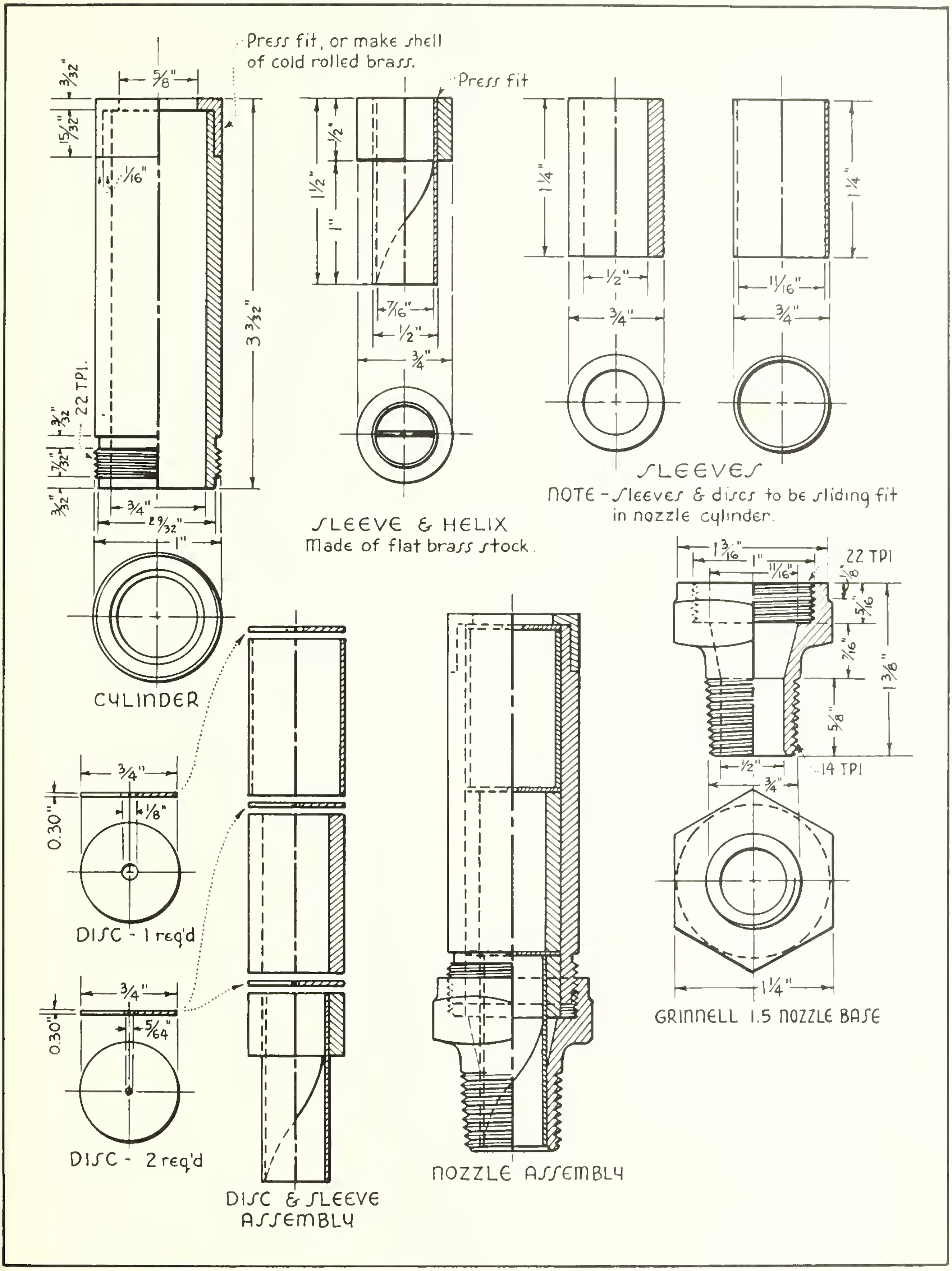

Figure 18.--Construction detail of type-F nozzle.

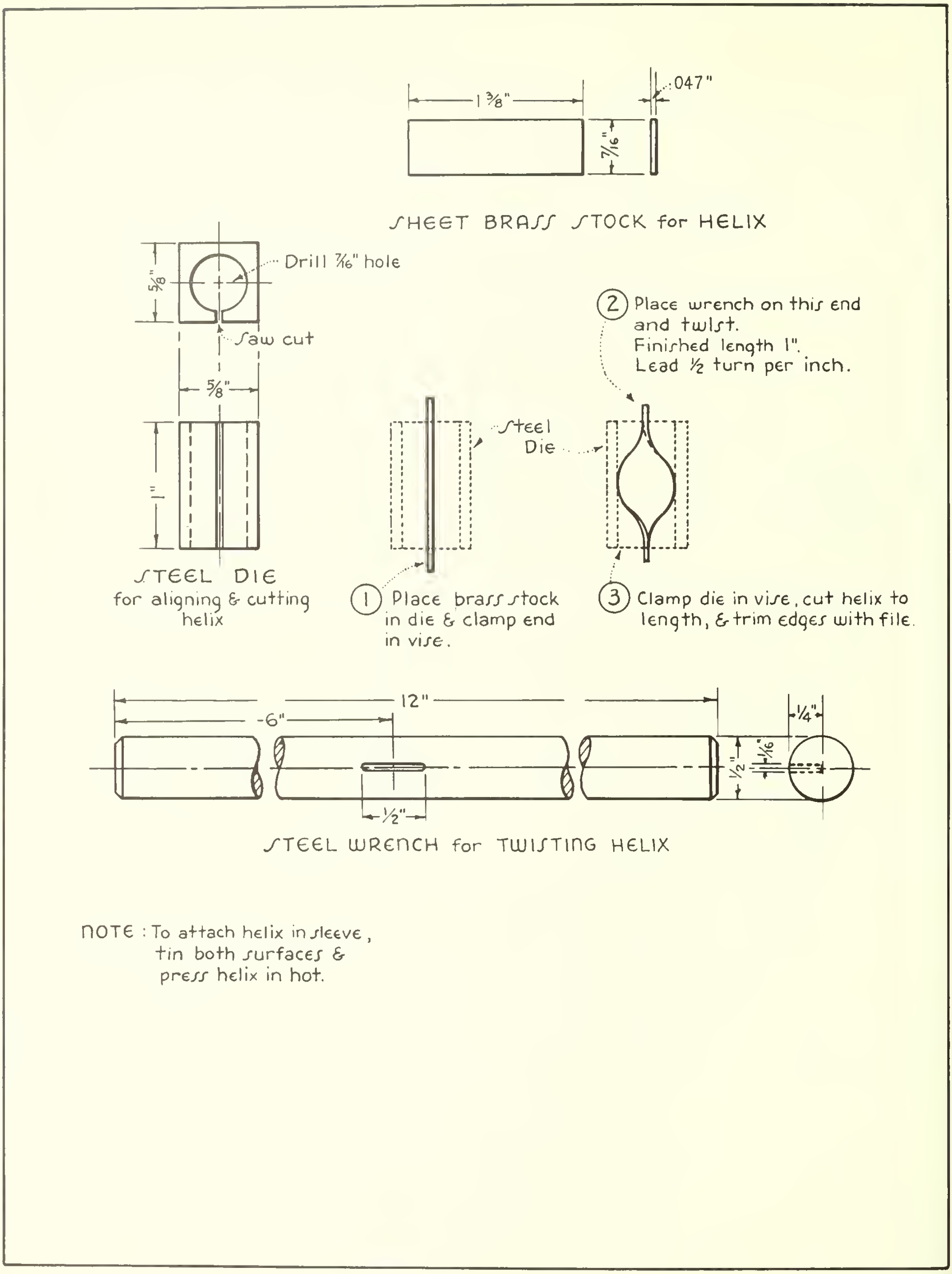

Figure 19.--Suggested method for making helix of type-F nozzle.

Four corner braces, 20" x 1" x 1/8" galvanized strap iron, tapped for 1/4" screws 1/2" from each end.

Four corner brace clamps, each of two pieces of 1/8" gage aluminum 4" x 2"; fitted together and tapped for three 1/4" friction screws and wingnuts (see fig. 6).

Eight draw bands, 8" x 1" x 1/16" galvanized strap iron; formed around 2" tubular portion of legs; tapped for 1/4" screws and wingnuts 1/2" from ends.

Thirty-two screws and wingnuts, 1/4" x 1/2" length.

Estimated total cost of rainfall applicator unit: $350.

Plot Unit

Plot Wall

One lower cutoff wall, 7' x 6", of 1/8" sheet steel.

One runoff sill, 6' x 1/2" x 6", of 1/8" sheet steel. Bend to 120-degree angle lengthwise to form 3"-wide spillway and 3"-wide vertical wall. Additional 3" vertical wall of same stock welded on underneath side of spillway to form 1/8"-wide slot for mounting on lower cutoff wall. Spillway notched out to vertical wall at 2' and 4' points and three separate spillways thus formed are separated by 1" x 3" flanges welded on at angle of 60 degrees to vertical wall; 6" x 6" flanges of same stock are welded on upper side of vertical wall at each end and at 2' and 4' points so they extend 3" above upper edge of spillways (see fig. 6).

Four side cutoff walls, 6' x 6", of 1/8" sheet steel. A 6" x 7" piece of same stock with a 6" x 1" x 1/8" separator strip welded on one end to fit over the four upper flanges of runoff sill.

One upper cutoff wall, 7' 1/2" x 6", of 1/8" sheet steel bent at 90° angle at points 6" from either end. A 6" x 6" piece of same stock is welded inside bend to form 6" x 6" x 1/8" slots to fit over upper ends of side walls. At points 2' and 4' from ends, 6' x 6' x 1/8" slots for inside side walls are formed by welding on four pieces of 6" x 9" x 1/8" sheet bent at 90° angle so that 3" is welding surface on the upper wall and 6" protrudes to form the slots (see fig. 7).

Plot Wall Driver

One plot wall driver, milled from spring steel 5'6" x 6" x 2". A slot 3/16" wide and 3" deep milled down the centerline on the narrow or 2" surface. This slot is widened to 1/2" for 4" on each end to receive flanged ends of cutoff walls. A 1/2" x 3" opening into the slot is milled on one side of the driver at points 21" from each end to fit over inside walls when using driver on upper cutoff wall.

One sledge hammer, either 8- or 12-lb. size.

Estimated cost of each plot unit: $30.

Windbreaker Tent Unit

Tent Frame

Four sliding legs, of fitted 2" x 1/8" x 6' aluminum tubing on outside and 1-7/8" x 1/8" x 5' aluminum tubing on inside. Inside tubing slotted lengthwise between points 6" from either end to receive 1/4" lock screw. Inside tubing forms lower part of leg and is equipped with 1/8" gage aluminum mud plate 8" in diameter and 1-7/8" diameter pointed steel spike in lower end. Outside tubing equipped with either triangular steel brackets or small sleeve brackets of steel at top end and at point 12" from lower end to which horizontal crosspieces are bolted. Outside tubing tapped at point 6" from lower end for 1/4" lock screw (see fig. 9).

Eight horizontal crosspieces, 11' long of 1-7/8" x 1/8" aluminum tubing, tapped near ends for 1/4" bolts for mounting on leg brackets. Four of these crosspieces have brackets similar to those on legs welded at their mid-points to receive two top crosspieces.

Two top crosspieces, 11' long of 1-7/8" x 1/8" aluminum tubing, tapped near ends for 1/4" bolts for mounting on upper horizontal crosspieces. These top crosspieces extend between upper opposite horizontal crosspieces to support top of canvas tent cover.

Four screws, 1/4" x 1", with wingnuts, for locking tent legs at any desired height.

Forty bolts, 1/4" x 2", with wingnuts, for mounting crosspieces on brackets.

Tent Cover

One tent cover, 11-1/2' x 11-1/2' x 9-1/2' high, of 8-ounce awning canvas with double-sewn seams and reinforced corners. Equipped with 12"-wide canvas sod-flap around bottom and 7' vertical opening down center of one side closed either by zipper or tent snaps (tent snaps preferable). Equipped with 12" x 12" openings protected by snap-fastened flaps in center of other three sides. Equipped with heavy web guy rope loops at each top corner and in center of each top edge.

Eight guy ropes, 1/4" x 15', ordinary hemp rope or nylon shock cord.

Eight guy stakes, 3/4" x 3/4" x 18", of angle aluminum, sharpened on one end, and equipped with loose 1/4" x 2" steel rivet near upper end for securing guy rope.

Estimated cost of windbreaker tent unit: $200.

Rainfall Collection and Measuring Unit

Rainfall Collection

Two rain gage troughs, 6' long, 1.8" wide (inside measure), and 3" deep, of 1.8" gage aluminum; welded watertight and adjusted precisely to 1/8" width on open top by five 1/4" x 2" screws through centerline of sides at each 1' point; equipped with 3/4" outlet and 3/4" x 2" hose-threaded nipple on one end welded flush with inside bottom; equipped with two 1" x 6" bent aluminum brackets at points 1' from each end for mounting on side cutoff walls; tops of sides beveled 45° to sharp inside edge (see fig. 11).

Two collector tubes, 6' long, of 5/8" aluminum tubing with 5/8" plastic hose connection on one end to 3/4" brass hose coupling; other ends joined into single tube by 5/8" aluminum tube Siamese fitting attached with short 5/8" plastic hose sections.

Rainfall Measuring

One calibrated rainfall can, 16.58" diameter, 12" deep, of 1/8" gage aluminum, with lid; equipped with small stilling well or baffle and brackets for holding staff gage.

One staff gage, 1' length graduated in 0.01' markers, of porcelainized steel.

Estimated total cost of rainfall collection and measuring unit: $30.

Runoff and Sediment Collection Unit

Collector Trough

Three collector troughs with lids, of 1/16" gage aluminum sheet, 23" long, 3" deep, 14" from straight upper edge to swedged funnel mouth. Lip along straight upper edge is 1" deep to fit under runoff sill. Funnel 1½" diameter equipped with 1½" aluminum collar 3" from end to divert rain drip from collector cans. Upper edge of lid equipped with 1½" x 23" aluminum strip mounted on three 1/4" lock screws for aligning to lower edge of plot (see fig. 10).

Samples

One sample case, 24" x 21" x 6", of wood construction, compartmentalized for 18 sample jars, with hinged or sliding side and suitcase handle.

Four graduates, standard 100, 250, 500, and 1,000 cc sizes of lucite to avoid breakage.

Six dozen sample jars, standard quart size fruit jars, glass or, if available, preferably lucite containers.

One stopwatch, graduated in seconds.

Total Discharge

Nine milk cans, 10-gallon size with lids, galvanized.

Estimated total cost of runoff and sediment collection unit: $150.

Runoff and Sediment Measuring Unit

Samples

Nine filter funnels, 8" diameter mouths, 1/2" diameter funnel, of galvanized 1/16" sheet steel, welded seam.

Filter paper supply, 10" diameter, medium weight.

One scales, triple-beam type, adjustable, weighs zero to 2,000 grams or more by 0.1 gram increments.

One oven, soil-drying type (if desired in lieu of filtering).

Total Discharge

Nine milk cans, 10-gallon size, with lids, galvanized.

Nine filter funnels, 24" diameter mouths and 1" diameter funnel, 24" high, of galvanized 1/16" sheet steel, welded seam.

Filter paper supply, 21" diameter, medium weight.

One scales, platform type, weighs zero to 200 pounds or more by 1/4-pound increments.

Estimated total cost of runoff and sediment measuring unit: $450.

Accessory Equipment

Calibration Accessories

Thirty-two tin cans, No. 2, galvanized.

One extra rainfall collector can, 16.58" diameter, 12" deep, of 1/8" aluminum sheet.

Sixty square feet of burlap splash dampening material.

Three oilcloths, 7' x 2'6" waterproof.

Pump Accessories

One extra rubber fuel line.

Four extra spark plugs.

Two extra starter ropes.

Two 5-gallon fuel cans, easy-pour spouts.

One drum, steel 15-gallon, with barrel faucet.

One grease gun, Alemite, for regular grease.

One grease gun, Alemite, for water pump grease.

Physical Measurements Accessories

One Abney level, graduated in "percent" scale.

One metallic tape, 100' length.

One tatum, aluminum, 8½ x 11" size.

Tool Kit

One chest, 24" x 20" x 18", wooden construction, hinged lid, two metal handles, compartmentalized as desired for smaller tools and accessories.

One pair grass shears, offset handles.

Three wrenches, Crescent 8", 10", and 12".

Two wrenches, Stiltson pipe, 10" x 14".

Two wrenches, $1\frac{1}{2}$" fire hose spanner type.

One pliers, 6"

One bolt cutter, 10"

One screwdriver, 8"

Two shovels

One pick

Estimated total cost of accessory equipment and tool kit unit: $100.

Estimated total cost of infiltrometer exclusive of transportation: $3,450.

Transport Unit

Two trucks, 1/2-ton capacity, stakeside racks, bed width 4 feet, bed length 6 feet, 4-speed transmission.

or, one truck, $1\frac{1}{2}$-ton capacity, stakeside, bed width 6 feet, bed length 12 feet, dual wheels, 4-speed transmission.

If needed for water hauling, one truck, $1\frac{1}{2}$-ton capacity with mount on bed for water tank, 4-wheel drive preferable.

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SILVICS of WESTERN LARCH

Botanical range of western larch.

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SILVICS OF WESTERN LARCH

By

Kenneth N. Boe
Forester

INTERMOUNTAIN FOREST AND RANGE EXPERIMENT STATION
Forest Service
U. S. Department of Agriculture
Ogden, Utah
Reed W. Bailey, Director

FOREWORD

As intensive forest management becomes progressively more widespread, silviculture will be the means by which the forest may be systematically and carefully manipulated. Silviculture can be fully successful only as the silvics of the species are available, appreciated, and applied in the process of removing mature tree crops and starting new ones.

The silvics of the more important North American tree species are being collected and published by the U. S. Forest Service experiment stations. This report is the second of seven including western white pine, ponderosa pine, lodgepole pine, western larch, western redcedar, grand fir, and black cottonwood being prepared by the Intermountain Forest and Range Experiment Station. The U. S. Forest Service is planning a single publication that will include the entire series for the United States.

Information in this publication is based on selected references and unpublished data through 1956. The author will appreciate having any omissions or apparent misinterpretations called to his attention.

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SILVICS OF WESTERN LARCH

By

Kenneth N. Boe[1/]

Western larch (Larix occidentalis), a deciduous conifer, occurs naturally only in the Upper Columbia River Basin of North America. This largest of American larches ranges from southeastern British Columbia throughout western Montana west of the Continental Divide to an area in the Bitterroot Mountains, 30 to 40 miles south of Missoula, thence to that part of Idaho generally north of the Salmon River and to northeastern Washington. Its range continues along the east slopes of the Cascades in Washington and north-central Oregon and in the Wallowa and Blue Mountains of northeastern Oregon and southeastern Washington (16, 32, 40).[2/]

First discovered on the upper Clearwater River in Idaho by the Lewis and Clark expedition in 1806, the tree was next reported by the Scottish explorer David Douglas on the Columbia River in northeastern Washington in 1827. Thomas Nuttall recognized the tree as a new species after observing it in the Blue Mountains of northeastern Oregon in 1834 and classified it in 1849 (41).

HABITAT CONDITIONS

CLIMATIC

Larch grows in a climatic zone having cool temperatures and an average annual precipitation of 28 inches, of which only 20 to 30 percent falls in summer (8, 19, 25). The minmum annual precipitation tolerated is about 18 inches. Rainfall of 35 inches is known in a few larch forests. Minimum precipitation of 2 to 3 inches occurs in July and August. The four months of May through August receive 5 to 7 inches. Peak precipitation of about 4 inches per month occurs in December and January in western Montana and just over 4 inches per month in November, December, and January in northern Idaho. Snowfall ranges from 40 to more than 80 inches (25). Mean temperatures in western Montana range from a low of 21° F. in January to 41° F. in April, and reach a peak of 60° F. in July. They then decline slightly to 57° F. in August, 43° F. in October, and about 23° F. in December. The same temperature pattern prevails in northern Idaho, but respective values are 2° F. to 3° F. higher. For 160 to 175 days during the year, mean air temperatures are above 43° F. (25). Frost is likely during every month of the year. However, the last spring frost usually occurs about the first week in June, and first fall frost occurs about the last of August or first of September (19). Temperature extremes range from -49° F. to 107° F. (25).

1/ Forester, formerly on the staff of Intermountain Forest and Range Experiment Station, U. S. Forest Service, Ogden, Utah.

2/ Underlined numbers in parentheses refer to Literature Cited.

EDAPHIC

Western larch grows best on deep, porous soils of mountain slopes and valleys that range in texture through gravelly, sandy, and all classes of loam soils (32). Extensive soil surveys within the type have not been made, but the soil association is generally classified as gray-brown podzolic (44). Moisture equivalent of the top 20 inches of soil in northern Idaho and adjacent Washington ranges from 23 to 45 percent, and pH from 5.50 to 6.40 (11).

PHYSIOGRAPHIC

This species characteristically occupies northerly exposures, valley bottoms, benches, and rolling topography. Southwest exposures ordinarily are not favorable sites for larch (8). It occurs in the middle elevation zone at 2,000 to 5,500 feet in the north and up to 7,000 feet in the southern part of its range (19, 32, 25, 41). Upward extension probably is limited by temperatures.

BIOTIC

Western larch occurs throughout the transition forest that is described as a peninsula of tree associates extending eastward across northern Washington and southern British Columbia and expanding north and south on the west slope of the Rockies (9, 30, 46). It has been classified as the climax Larix-Pinus association of the Thuja-Tsuga formation (46), but elsewhere as a subclimax species held rather indefinitely, chiefly by fire (30). Another ecologic concept is that western larch is a seral or temporary species at least in northern Idaho and adjacent Washington and perhaps in western Montana (11). In this area larch is considered a major seral species in the following associations, or basic units of climax vegetation that are named for the distinctive vascular plant groups of vegetation, or unions, comprising each: (1) Picea-Abies/Pachistima; (2) Thuja-Tsuga/Pachistima; (3) Thuja/Pachistima; (4) Abies grandis/Pachistima; and (5) Pseudotsuga/Calamagrostis. It is a minor seral species in (1) Picea-Abies/Menziesia; (2) Picea-Abies/Xerophyllum; and (3) Pseudotsuga/Physocarpus.

Classified on the basis of forest cover type now occupying the ground, larch is an important dominant in the larch--Douglas-fir (Pseudotsuga menziesii) grand fir (Abies grandis)-larch--Douglas-fir, and ponderosa pine (Pinus ponderosa)-larch--Douglas-fir cover types. It is an important associate in the western white pine (Pinus monticola) cover type (39). Within these types larch is generally regarded as a subclimax species owing its maintenance to fire, although in places it tends to remain rather stable.

The larch--Douglas-fir forests are found commonly in northern Washington, Idaho, Montana, and southeast British Columbia. Minor associates in the stand are lodgepole pine (Pinus contorta), grand fir, western white pine, ponderosa pine, western redcedar (Thuja plicata), and subalpine fir (Abies lasiocarpa). Along the eastward limits of the type, western larch is replaced by interior Douglas-fir. Of the many shrubs and herbs, Pachistima myrsinites, Vaccinium membranaceum, Menziesia ferruginea, Chimaphila umbellata, Rubus parviflorus, and Linnaea borealis are usually numerous and characteristic in this cover type.

The grand fir-larch--Douglas-fir combination is found along the east slopes of the Cascade Range, the Okanogan highlands in northern Washington, and in Idaho, Montana, and northern Blue Mountains of Oregon. Associates are usually western hemlock (Tsuga heterophylla), western white pine, Engelmann spruce (Picea engelmannii), and ponderosa pine. Pachistima occurs in this type as well as Berberis nervosa, Corallorrhiza maculata, and Physocarpus malvaceus.

In the mixture of ponderosa pine-larch--Douglas-fir, ponderosa pine is an indicator species present in significant amounts but not predominating. It occupies intermediate zones in western Montana, Idaho, eastern Oregon, and Washington between the ponderosa pine and moister larch--Douglas-fir. Grand fir, western white pine, and lodgepole pine are sometimes present in minor amounts. Characteristic shrubs and herbs are Physocarpus malvaceus, Calamagrostis rubescens, Amelanchier alnifolia, and Arctostaphylos uva-ursi.

Finally, in the western white pine type of northern Idaho, Montana, and British Columbia, larch is often an important associate. Pachistima is present as a characteristic shrub together with Rubus parviflorus, Vaccinium membranaceum, and the herbs Clintonia uniflora and Adenocaulon bicolor.

LIFE HISTORY

SEEDING HABITS

Flowering and fruiting.--Male and female flowers, borne singly and separately from each other on the same branches or twigs of the previous or an earlier year's growth, appear with the new leaves. Pollen-bearing flowers are budlike yellow-green organs about the size of a small pea. Female flowers are similarly small, elongated, purple or red, and composed of tiny scales each bearing two minute ovules (41). Flowering was observed to be well advanced in one instance on May 11 at 3,000 feet elevation on rolling terrain at latitude 48°20' N., near Kalispell, Montana.

Cones, which mature in a single season, average 1 to 1½ inches long. They ripen by the end of August and early September, and seed is shed during favorable periods afterwards. Cones fall from the trees throughout the following winter, but frequently substantial numbers remain through the next summer.

Seed production.--Seed is produced only infrequently before age 25 (29), but at age 40 to 50 larch bear abundantly and continue to bear for 300 to 400 years (41). In any stand only the codominant and dominant trees produce significant amounts of seed.

Although about 80 seeds may be produced by a mature cone, the number of full-sized, sound seed characteristically totals fewer, frequently only one-half this number. During an excellent seed year sawtimber-size trees produce

22,000 sound seeds per tree (37). Trees averaging 22-inch d.b.h. potentially will produce five times the volume produced by trees averaging 14 inches (36). At the rate of 143,000 seeds per pound (45), sawtimber trees may average one-seventh pound of seed in an excellent seed year.

Based on frequency of cone crops, larch rates as a good seed-producing species. Records over a 22-year period, covering a major portion of the larch type, indicate that a ratio of one fair or good cone crop to one poor crop is characteristic (4). This same ratio prevailed for a 6-year period on the Coram Experimental Forest in northern Montana. Nevertheless, a fair or good crop does not always immediately follow a poor crop. As many as five consecutive fair or good crops and four consecutive poor crops may develop (4). Intervals between good crops averaged 4.7 years over a 14-year period in the western white pine type (15), but at Coram Experimental Forest an outstanding crop in 1954 matured after an interval of one year following the good crop in 1952.

The amount of sound seed available per acre depends on such factors as abundance of cones, whether seed is weeviled or empty, and number of cone-bearing trees per acre. Seed-tree cuttings on Coram Experimental Forest, on which there were 4 to 5 codominant and dominant trees plus an additional 12 smaller trees per acre, produced as follows:[3/]

Year	Number sound seeds per acre
1949	43,000
1950	17,400
1951	400
1952	400,078
1953	5,600
1954	701,726

Percent soundness of larch seed probably correlates directly with size of crop. From the yields reported above, only 9 percent of the poorest seed crop was sound, but the percentages increased progressively to 16 and 30 percent for fair crops and to 32 and 38 percent for the best crops produced.

Seed dissemination.--Most seed is normally shed in the fall soon after ripening. At Coram Experimental Forest, latitude 48°25' N. and for an average elevation of 3,700 feet, 19 percent of the sound seed was dispersed by mid-September, another 65 percent by mid-October, 15 percent throughout the remainder of the fall, winter, and spring, and 1 percent the following summer.[4/] Seasonal dispersal of larch seed in northern Idaho paralleled these findings that two-thirds or more of the seed is shed by late fall. Additional evidence may be needed to verify whether the greater percentage of seed dispersed

3/ Unpublished results from seed dispersal study on the Coram Experimental Forest.

4/ Ibid.

earlier by a young stand, as shown in the following tabulation (15), is a consistent characteristic.

Period	Seasonal dispersal of seed from: 300-year-old stand	75-year-old stand
	Percent	Percent
Midsummer to August 31	5	24
September, October	61	54
November 1 to midsummer	34	22

The small seed (143,000 per pound) aided by a favorable wing-seed ratio is carried substantial distances by wind, the principal dispersal agent. The quantity of sound seed decreases rapidly from a timber edge to an effective seeding distance of 400 feet (three tree heights) and then remains somewhat constant at a very low level at least to 792 feet from the source. Only about 5 percent of the total sound seed produced is likely to reach beyond 400 feet (3).

VEGETATIVE REPRODUCTION

Larch does not reproduce by sprouts. Although techniques for rooting cuttings have not been reported, it seems likely they could be developed. A few successful veneer grafts have been produced by the Intermountain Station.

SEEDLING DEVELOPMENT

Establishment.--Western larch seed rates fair in viability. An average germination percent of 39 for fresh seed was calculated from four reported germination tests: the average percentages reported were 30 (28), 60 (22), 47 (23), and 19 (43). In comparison, Douglas-fir averaged 45 percent based on reported germination percentages of 49 (22), 49 (23), and 41 (28). Elsewhere, germinative capacity of 27 percent, ranging from 0 to 65 percent, was calculated from 25 tests (45).

Larch seed loses vitality under artificial storage at about the same rate as its important associates. Germination of seed stored in glass-stoppered bottles in a room heated during cold-month days and unheated at night decreased 6 percent annually for 5 years after collection. Douglas-fir decreased 7 percent annually for 4 years and Engelmann spruce 2.5 percent for 5 years (23).

Germination is little affected by seedbed under controlled greenhouse environment (12) but greatly affected by seedbed in the forest. Based on duff as 100 percent, germination of larch was reported as 199 on burned-over seedbed and 320 on mineral soil (15). In contrast, Douglas-fir germination was about equal on all seedbeds. Elsewhere, both larch and Douglas-fir were reported to have germinated best on burned surfaces. Only 4 percent germinated on duff, 13 percent on mineral soil, and 20 percent on ashes (24, 26). Poor germination on duff, especially of the small-sized larch seed, likely is caused by the rapid drying of the organic material.

Germination of larch seed is believed to begin when soil temperatures reach 60° F. and proceeds rapidly at temperatures of 70° to 80° F. All associates of larch responded similarly in these temperature ranges (23). In northern Idaho germination began April 28 in the open and May 20 in full shade and was mostly completed by June 5 and July 15, respectively (15). Germination probably starts a week to a month later at higher elevations and on shaded north slopes.

In the first critical growing season, survival of larch ranges from nil to about 80 percent; it averaged 54 percent in one test (15). Biotic agents cause principal mortality soon after germination. Later deaths are caused primarily by environmental factors. The effects vary by seedbed, topographic situation, and character of occupying vegetation.

Early first-year seedling losses to fungi, the greatest biotic factor, rank unusually high on duff (as compared to mineral soil) in full sun and part shade on river flats and benches. The reverse appears to be true under full shade. Douglas-fir is affected similarly under full sun and full shade, but differs under part shade as shown in the following tabulation (14):

	Mortality from fungi in percent of total seedlings on each seedbed					
	Full sun		Part shade		Full shade	
	Duff	Mineral	Duff	Mineral	Duff	Mineral
Larch	96	14	70	7	30	61
Douglas-fir	97	33	37	38	19	66

Larch succumbs to other biotic agents, but insolation usually ranks as the second major cause of death as the growing season advances. Furthermore, duff is again the least desirable seedbed. Lethal temperatures occur earlier and for many more days on duff during the growing season. Duff temperatures reached 120° F. on 76 days and 135° F. on 43 days. On mineral soil 120° F. occurred for only 8 days, and 135° F. was never recorded in full sun on slight north slopes. The tabulation below indicates the probable losses for the different conditions except duff in full sun, for which there were no residuals. Of course, no insolation losses were experienced in full shade (14).

	Mortality from insolation in percent of residual seedlings			
	Full sun		Part shade	
	Mineral	Duff	Mineral	Duff
Larch	75	No residuals	24	52
Douglas-fir	81		14	44

Later in the growing season and after stems harden, larch losses are generally due to drought. Anomalously, losses are greatest where moisture depletion is least in the heavily shaded condition. As shown in the tabulation below, the large losses in full shade are undoubtedly due to extremely short roots. Douglas-fir, grand fir, and white pine survive much better in shade. Root penetration averaged 1 inch for larch compared to 2½ inches for Douglas-fir. But in full sun and part shade roots of both larch and Douglas-fir frequently penetrate below soil layers that have depleted moisture (14).

Mortality from drought in percent of residual seedlings

	Full sun	Part shade	Full shade
Larch	4	2	93
Douglas-fir	5	1	17

Representative larch seedling losses computed by averaging counts from all sedbeds on cutover areas in northern Idaho approximate 46 percent the first year and 67 percent for 6 years. Douglas-fir losses are similar to these (15).

Survival of larch is poor to nil on xeric southwest exposures within the geographic zone of its occurrence (21). On these same slopes Douglas-fir becomes established successfully as the dominant species.

Not only is mineral soil a superior seedbed, but reduced vegetative competition also favors larch. Numbers of seedlings have been reported to be doubled on habitats supporting light-density, low vegetation over heavy-density cover; they were tripled on areas where shrubs and small trees had been removed, as compared with areas where they had not been removed (35). Furthermore the average number of sound larch seed needed to produce one established seedling varies from 26 on mineral seedbeds to 191 on the forest floor (37).

Natural regeneration of larch is favored, then, by cutting methods that provide substantial to complete removal of overhead growth and exposure of considerable mineral soil. Such harvest cutting methods as seed-tree, shelterwood, and clear cutting in blocks or strips are appropriate. Removal of vegetative competition and exposure of favorable seedbed can be accomplished by prescribed burning, bulldozer piling of slash and burning, and normal logging disturbance. The superiority of one method over another depends on conditions within a given stand. When successfully completed, all these methods produce desirable even-aged stands.

Early growth.--One-year-old larch averages about 2 inches in height. Shaded seedlings are puny and have only inch-long roots, but sturdier seedlings growing in part shade and full sun have roots about 9 inches long. Top growth of partly shaded seedlings is generally twice that of plants growing in full sun. Partly shaded Douglas-fir and grand fir also are larger than seedlings grown in full sun. However, total weight of tops and roots of seedlings growing in full sun probably averages more than those in part shade (14). Larch, in common with other seedlings, initially grows faster on burned seedbeds because of availability of additional nutrients. Characteristically, after the first few years, larch, lodgepole pine, Douglas-fir, and white pine all grow best under full sun.

In favorable situations, western larch grows rapidly in height beginning the second year; sometimes it attains a height of 4 feet in 4 years. Only lodgepole pine can match juvenile height growth of larch where both are growing on the same site. Early height growth of Douglas-fir is about one-half and Engelmann spruce about one-fourth the growth of larch (16, 19).

Needle and shoot growth starts in April or May and is practically complete by July (6). Single needles on new seedlings persist for one or more years. Single needles on new shoots, however, are mostly deciduous, as are the needle clusters of 14 to 30 needles each on older shoots.

SAPLING STAGE TO MATURITY

Growth and yield.--Larch grows rapidly in height and moderately in diameter until ages 75 to 100 years. On the same site, only lodgepole pine equals larch in height growth during early years, but eventually larch outstrips the pine. Annual height growth averages 1.5 feet between ages 14 and 20 (6). Both larch and lodgepole may attain 19 feet in 15 years, since they may add as much as 30 inches annually (8). Average heights of larch attained at different ages are as follows (21):

Age (years)	10	30	50	70	90	120
Height (feet)	12	33	50	65	77	90

Diameters may reach 16 inches at 80 years under favorable conditions, but radial increment characteristically declines thereafter. Frequently 250-year-old stands average only 16 to 24 inches in diameter (41) and 400-year-old stands 30 inches (21).

Radial growth begins at low altitudes usually in April, but is delayed a month or more at high altitudes and cool sites. Growth began April 19 at an elevation of 3,238 feet in Idaho in 1942; it did not begin until May at an elevation of 4,822 feet. Growth at low levels substantially surpassed that at higher levels; however, seasonal culmination occurred about mid-July at both elevations. During the dry period in late summer, radial shrinkage occurred, but original dimensions were regained and surpassed after fall rains (10).

Larch is a long-lived tree and may attain large sizes. Many trees in the Seeley Lake grove in Montana are more than 700 years old and measure more than 60 inches d.b.h. The largest tree measured was 88 inches d.b.h. One windthrown monarch was determined to be 915 years old. Two medium-sized trees had 595 and 715 rings (20). The largest tree reported, however, was found on the

An extensive stand of immature western larch and lodgepole pine which became established following a fire.

Kootenai National Forest in northwestern Montana. It measured 91 inches d.b.h. (1). Trees 175 feet in height have been measured on growth plots at Coram Experimental Forest. In a 380-year-old stand, tallest trees were 175 feet high and 55 inches d.b.h. (21).

The expected yield of larch stands probably ranks high. A volume of 60,000 board feet per acre for a 380-year-old stand has been reported (21). However, many other stands have contained volumes of 20,000 board feet and less. The following tables of available yield information show that estimation varies widely and indicate the need for some additional checking to establish the approximate range of yields.

Reaction to competition.--Larch is intolerant of shade through its entire life except in the early seedling stages; then it tolerates partial shade (2, 15). It is the most intolerant of its associates. Unless full sunlight is provided by removal of overhead competition, larch loses dominance to the more tolerant species (15). Where advance growth of other species is husbanded as future growing stock, decline of larch from a dominant position is hastened. Harvest cuttings tend to favor establishment of larch, but the rapid development of any advance growth precludes much of the new reproduction becoming dominant (31).

Table 1.--Probable average yield of larch stands (42)[1/]
(Minimum size not given)

Site class	Average height dominant and codominant age - 100	Volume per acre at:		
		100 years	140 years	200 years
	Feet	Bd. ft.	Bd. ft.	Bd. ft.
I	92	23,500	38,000	--
II	84	15,500	26,000	--
III	75	9,100	15,000	--

1/ Data from Kootenai National Forest.

Table 2.--Probable average yield of larch stands in the larch--Douglas-fir type (7)

(Trees 13.0 inches d.b.h. and larger--fully stocked)

Site class	Average height dominant and codominant age - 100	Volume per acre at:		
		100 years	140 years	200 years
	Feet	Bd. ft.	Bd. ft.	Bd. ft.
I	121	43,500	69,800	94,600
II	107	25,400	51,200	74,500
III	94	11,200	29,100	51,600
IV	80	4,000	10,200	23,100
V	66	300	2,000	6,000

Trees more than 200 years old respond to cutting release. Where cutting is heaviest, individual trees make the greatest response, but within a wide release category afforded by a seed-tree or shelterwood cutting, response is correlated directly with vigor (34). Larch makes relatively better response than Douglas-fir in fair- and good-vigor classes; however, Douglas-fir usually exceeds larch in actual growth. Trees in the best-vigor group grow nearly one and one-half times as much volume as the average; medium-vigor grow slightly less than the average; and the poorest group grow only one-half of average volume (33).

A pure stand of mature western larch.

Larch competes not only with trees of similar size but also with the tolerant understory that develops under the somewhat open-crowned trees. Diameter growth of residual larch on a seed-tree cutting increased 67 percent over prelogging growth. Cutting of all understory trees resulted in an additional increase of 36 percent of prelogging. Douglas-fir accelerated 42 percent over prelogging after cutting but did not make an additional response after removal of the understory because it probably already fully occupied the site (38).

Trees 50 years old respond to release by growing new branches from adventitious buds. The rate of occurrence and degree of regrowth are correlated directly with amount of release. Adventitious branches developed on pruned sections of 54 percent of larch crop trees released by a heavy grade of thinning, but only on 24 percent released by a medium grade. Branches tended to develop in the upper half of pruned sections of the former group and in the upper quarter of the latter. Before pruning, fine dead branches persisted throughout the butt log.[5/]

INJURIOUS AGENCIES

Fire resistance of mature and older larch exceeds that of any of its associates. However, young trees of sapling and pole size are killed readily by fire. The basal bark of older trees is at least 3 to 6 inches thick and affords protection against fire (8, 41).

Larch trees are moderately resistant to windthrow because of excellent anchorage afforded by their deep, wide-spreading root system (16).

Dwarfmistletoe (*Arceuthobium campylopodum* forma *laricis*) is a serious disease of larch. It may infect trees from 3 to 7 years of age, continuing throughout the life of the tree. Mistletoe enters shoots 4 years old or younger (47). "All mistletoe infections interfere with normal functioning of a tree and are therefore detrimental" (13). Slight infections may reduce growth to three-fourths of average, and severe infections may reduce growth to one-half of normal in young trees (13). Infected trees 144 years old averaged 63 feet in height and 11.5 inches d.b.h., while uninfected trees averaged 115 feet in height and 19.5 inches d.b.h. Besides reducing growth, mistletoe kills outright, causes spiketops, creates entrances for insects and fungi, causes burls and brashness, and reduces vitality of seed (47).

Larch is afflicted by three other important diseases: the brown trunk rot caused by the quinine fungus, *Fomes laricis*; red ring rot caused by *Fomes pini*; and needlecast caused by *Hypodermella laricis* (5).

Among the most damaging insects to larch are the sawfly, *Pristiphora erichsonii* and bark beetle, *Dendroctonus pseudotsugae*. The spruce budworm (*Choristoneura fumiferana*) infrequently attacks larch, and the larch bud moth (*Zeiraphera griseana*) damages extensively but sporadically. The western larch sawfly (*Anoplonyx occidens*) has been credited with a single damaging attack. The sawtooth pine engraver (*Ips integer*) usually attacks dying and felled trees (18). Other minor pests cause infrequent damage.

5/ Unpublished results of crop tree thinning and pruning experiment in a 50-year-old larch stand, Missoula Research Center, Intermountain Forest and Range Experiment Station.

SPECIAL FEATURES

Galactan, a water-soluble gum that is present in western larch, distinguishes this wood from other softwoods. This gum is concentrated in the basal portions. The end product of galactan, mucic acid, can be used in manufacturing baking powder (17).

The oleoresin produced by western larch can be used commercially in the same ways that the oleoresin of European larch is used. The western larch product has the consistency of honey, is light amber in color, and has a slightly bitter taste but an agreeable odor. It contains 16 percent volatile pinene and limonene. The nonvolatile portion is a resin possessing acid properties but yielding no crystalline product (27).

RACES

Races of western larch have not been reported. Few, if any, races seem likely because larch grows within a rather narrow geographic range.

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SILVICS of BLACK COTTONWOOD

Botanical range of black cottonwood.

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SILVICS OF BLACK COTTONWOOD

By

Arthur L. Roe
Forester

INTERMOUNTAIN FOREST AND RANGE EXPERIMENT STATION
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FOREWORD

The SILVICS OF BLACK COTTONWOOD is the third publication in the series of seven silvics manuals being published by the Intermountain Forest and Range Experiment Station as part of a larger project sponsored by the U. S. Forest Service. Forest Service Experiment Stations over the Nation are issuing similar bulletins on many important North American tree species. Eventually a single publication that will include the entire series will be issued by the U. S. Forest Service.

Information in this publication is based on selected references and unpublished research data through 1957. The volume of published literature on the black cottonwood is relatively small; hence the author has had to rely heavily on unpublished data. He will appreciate having any omissions of source material called to his attention.

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SILVICS OF BLACK COTTONWOOD

By

Arthur L. Roe[1/]

Black cottonwood (Populus trichocarpa) is the largest of the American poplars. It grows to greatest size in the forests of the Pacific Northwest, where it is the largest hardwood in the region (7, 8).[2/] Trees have been reported to reach a maximum diameter of 8 feet and a height of 175 to 225 feet. However, in many parts of its range it rarely exceeds 100 feet in height (8). Not only is it distinguished by its large size, but it also exceeds all of its associates in rate of growth (16). Black cottonwood has the greatest altitudinal range in any given latitude of any tree on the North American continent. For example, in Monterey County, California, it is found at only 50 feet above sea level, while at approximately the same latitude in the Sierra Nevadas it is found growing at 8,000 to 9,000 feet above sea level (2).

Black cottonwood is known by several other common names, including California poplar, cottonwood, balsam cottonwood, and western balsam poplar (8). Some taxonomists have distinguished a variety, northern black cottonwood (P. trichocarpa var. hastata). However, this variety has not been accepted generally because the characteristics separating it from the species are too variable (13). The new Forest Service check list (10) shows P. trichocarpa as the accepted name.

The range of this species extends along the Pacific Coast from Cook Inlet, Kodiak Island, and southeastern Alaska to southern California and northern Lower California, Mexico. In Alaska this tree is most common from Stikine River north to the head of Lynn Canal at Skagway; from Glacier Bay and Yakutat Bay west to Prince William Sound, Cook Inlet, and Kodiak Island. It is widely distributed throughout British Columbia, except east of the Rocky Mountains in the northeastern part of the province; its range extends eastward into southwestern Alberta (south of the Oldman River) and to south-central Montana--its easternmost extension--and central Idaho and western Nevada. It is found mostly on bottomland, river bars, and forest meadows and streambanks, but it occurs throughout the plateau lands in north-central British Columbia (3, 6, 8, 10, 13, 18, 20, 23).

1/ Forester, Intermountain Forest and Range Experiment Station, U. S. Forest Service, Missoula, Montana.

2/ Underlined numbers in parentheses refer to Literature Cited.

HABITAT CONDITIONS

CLIMATIC

Black cottonwood grows under extremely varied climatic conditions because of its great latitudinal and altitudinal range. Weather records from selected locations where cottonwood grows show that it occurs in relatively arid to humid climates (22). It develops best in a humid climate such as that found in the Pacific Northwest. In arid climates, away from the influence of sea and fogs, it shows much poorer development (7, 19).

The climate where black cottonwood occurs has great temperature ranges. Maximum temperatures range from 59.9° F. to 117° F., and the minimum temperatures range from 32.5° F. to -53° F. Average annual July temperatures from 53.4° F. to 75.9° F. are encountered, but average January temperatures may be as low as 46.6° F. to 17.7° F. Length of growing season within its range varies from 72 days to 263 days. The average annual precipitation, likewise, shows considerable variation, ranging from as little as 9.87 inches to as much as 126 inches. Much of this precipitation falls as snow since usually only about one-third of it falls during the season from April through September (22). These variations in climate indicate that other factors, including subsurface sources of soil moisture, strongly influence the distribution of black cottonwood.

EDAPHIC

Black cottonwood grows in a variety of soils ranging from moist gravelly and sandy, to rich humus soils and even some clay soils. On poor, dry sites it is somewhat dwarfed. The largest trees grow at low elevations on deep alluvial soils. At higher elevations it occurs in moist sandy, gravelly, or loam soils and is usually much smaller (7, 8, 10, 17, 19).[3/] In Glacier County, Montana, black cottonwood is restricted generally to loam soils along streams and around ponds (11). Black cottonwood requires a generous quantity of soil moisture throughout most of its growing season. Studies made by Smith in British Columbia (16, 17) point out that black cottonwood requires abundant moisture, nutrients, and oxygen in combination with a high pH for optimum growth. Furthermore, these requirements are usually met by a combination of factors such as soil texture, proper nutrient content, porosity, soil depth, and depth to water table.

Such nutrient elements as nitrogen, potassium, and phosphorus are usually present in sufficient quantities in most loam and clay soils to support good growth. However, some marshy soils and peat bogs may not contain enough calcium, which is a required nutrient. Optimum pH is believed to lie between 6.0 and 7.0, depending upon the nutrient composition of the soil. Soils having

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3/ See also: U. S. Forest Service. *Populus trichocarpa* as occurring on the Modoc National Forest. 4 pp. (Typewritten) n. d.

a pH of less than 5.5 may not support good growth. Best growth occurs on soils of agricultural quality. Canadian studies (16, 17) further point out some limits of conditions for good growth as follows:

1. At least 18 inches of loam or heavier soil is required for good growth if this soil is underlain by gravel.

2. Lack of aeration limits growth. Stagnant pools and fine sediment deposited by flooding tend to reduce aeration and shorten the effective period of growth. Fine sediment also slows percolation of summer rains. Conversely, flooding by fast-moving water rich in oxygen speeds growth.

3. Summer drought may affect growth if stands occur on sand ridges that have been cut off from the main water channel.

4. Soils frequently flooded may be young and poorly developed, and the site quality may change each time flooding occurs. The poorest quality soil is found in newly formed gravel bars.

5. The best soil is deep, fine-textured material, that is, topographically higher than average but still subject to flooding in very high water.

6. Some upland soils can produce excellent growth of black cottonwood. These include: wind- or river-deposited soil that has good supplies of calcium and other nutrients when they receive abundant rainfall; glei type soils if the glei layer is fairly deep and if the pH is reasonably high; soils in depressions and on lower slopes where moving ground water, rich in oxygen and nutrients, is present; loam and loamy sands belonging to the "brown soil" group only when they have an abundant supply of nutrients; and heavy clay soils only if their structure is modified by incorporated humus.

Typical habitat for black cottonwood where soil moisture remains high through growing season. Occasional flooding occurs in high water.

PHYSIOGRAPHIC

In the northern end of its range, on the Kenai Peninsula in Alaska, black cottonwood occurs from sea level up to 2,000 feet elevation; up to 5,000 feet in Washington; and up to 7,000 feet in the valleys of the Selkirk Mountains in British Columbia (19). In the southern end of its range, in California, it is most abundant from 3,000 to 6,000 feet, but it occurs up to 9,000 feet. In California it is generally found in the higher valleys and canyons. In the drier areas the effect of physiography is striking, because there black cottonwood usually grows in protected valleys and canyon bottoms, along streambanks and edges of ponds and meadows, and on moist slopes at the foot of the mountains where the roots can reach a relatively permanent supply of soil moisture. In humid areas its distribution is not influenced as greatly by physiography (7, 11, 19, 23).

BIOTIC

Black cottonwood is found from the upper Sonoran through the Canadian life zone and is represented in five western forest cover types (13, 18). It forms limited pure stands or groups usually on newly formed river bars or bottomlands. It occurs in mixture with Douglas-fir (*Pseudotsuga menziesii*), western white pine (*Pinus monticola*), western larch (*Larix occidentalis*), subalpine fir (*Abies lasiocarpa*), white spruce (*Picea glauca*), Engelmann spruce (*P. engelmannii*), western redcedar (*Thuja plicata*), western hemlock (*Tsuga heterophylla*), white fir (*Abies concolor*), red alder (*Alnus rubra*), Sitka alder (*A. sinuata*), vine maple (*Acer circinatum*), bigleaf maple (*A. macrophyllum*), several birches (*Betula* spp.), and many willows (*Salix* spp.), aspen (*Populus tremuloides*), Oregon ash (*Fraxinus latifolia*), black hawthorn (*Crataegus douglassii*), and other bottomland species. It is found in the ponderosa pine-sugar pine type and Jeffrey pine-red fir type in California. Black cottonwood meets with balsam poplar (*Populus balsamifera*) in Alaska and in the Yukon Territory and northeastern British Columbia, and the plains cottonwood (*P. sargentii*) in western Alberta and central Montana (6, 7, 8, 11, 16, 18).

Ecological studies made in Glacier County, Montana, by Lynch (11) recognized a *Populetum-Osmorhizetosum* association. The most prominent plants were *P. trichocarpa*, *P. tremuloides*, *Osmorhiza occidentalis*, *Viola canadensis*, *Smilacina stellata*, *Pedicularis bracteosa*, and *Heracleum lanatrum*. Aspen predominated in the drier extensions, whereas black cottonwood overtopped and outnumbered it on sites that were moister than normal.

In Inyo County, California, such plants as aspen, *Salix* spp., California black oak (*Quercus kelloggii*), interior live oak (*Q. wislizenii*), water birch (*Betula occidentalis*), cascara buckthorn (*Rhamnus purshiana*), and *Cornus* spp. are common associates.[4/] On the Modoc National Forest, California, *Salix* spp.,

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4/ Berry, James B. Black cottonwood. U. S. Forest Service Silvical report. 4 pp. (Typewritten) 1911.

aspen, Pacific dogwood (Cornus nuttallii), Klamath plum (Prunus subcordata), and common chokecherry (P. virginiana) are the predominant species found associated with cottonwood.[5]

Investigations in British Columbia by J. H. G. Smith and associates have demonstrated the feasibility of using indicator plants found among the lesser vegetation to indicate site quality. Smith was able to classify the stands into three broad site classes as follows:

Good site quality.--Salmonberry (Rubus spectabilis)-stinging nettle (Urtica spp.)-fern site. At least one of the above-designated plants must be present in some quantity. The fern may be either swordfern (Polystichum munitum) or ladyfern (Athyrium felix-femina). Vigorous growth of hazel and elderberry shrubs also seems to be associated with an excellent growth of cottonwood.

Medium site quality.--Red-osier dogwood (Cornus stolonifera)-black twinberry (Lonicera involucrata) and waxberry (Symphoricarpos alba) form the dominant element of the shrub layer. Thimbleberry (R. parviflorus) and wild rose (Rosa mitkana) are also commonly found on this site.

Poor site quality.--This site is often indicated by the common horsetail (Equisetum arvense). Land of this site quality is usually much below average quality and is subject to flooding for as much as 6 weeks in an ordinary year. The common horsetail and the tall horsetail (E. hymenale) do not always indicate poor sites because they may be present on layers of clay deposited over fine sand or silt on higher ridges or edges of water courses which may be of medium or better quality. In a few areas, poor and scrubby growth of the medium site indicators has been associated with soil layers deposited over poor site quality lands.

The above site classifications are analogous to those developed in Germany.[6] The good site class is somewhat better than German site class I, and the fair and poor site classes correspond generally with German site classes II and III, respectively (17).

According to Smith presence of the following additional species may give some clue to good growth potential for black cottonwood: jewelweed, hedgenettle, enchanters-nightshade, golden saxifrage, buttercup, bittercress, angelica, loosestrife, bedstraw, cleavers, giant fescuegrass, and tall hairgrass (16). On the other hand, he states that the presence of tall reedgrass, iris, spirea, or sphagnum moss may indicate acidic and excessively moist ground

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5/ U. S. Forest Service. op. cit.

6/ Site data are from Hesmer's Das Papelbuch; they have been verified by extensive sampling in British Columbia and are cited by Smith (17).

where conditions are not suitable for the cultivation of black cottonwood (17). Furthermore, he points out that cottonwood may not show good growth on lands occupied by some members of the willow family. But land currently supporting good stands of red alder is almost always capable of growing a much better crop of cottonwood than alder (16).

LIFE HISTORY

SEEDING HABITS

Flower and fruiting.--Flowers of black cottonwood are dioecious with both sexes borne in aments that usually appear before the leaves (11). They may begin to form from April 10 until May 30 in Washington and Oregon, and sometimes as late as June 10 in Montana and Idaho. The fruit is ripe in Washington and Oregon between May 24 and June 27, but in Montana and Idaho some years it has not ripened until mid-July.[7/] These dates may be earlier in the most southerly extremities and later in the northern extremities of the tree's range.

Seed production and dissemination.--Black cottonwood is generally a prolific annual seed producer The seed is light and buoyant and can be transported long distances by wind and water (7, 8).[8/] Natural seed dispersal begins from late May to early July, depending upon the lateness of the season and the locality.[9/]

VEGETATIVE REPRODUCTION

Black cottonwood sprouts readily both from stumps and roots.[10/] Although some observers believe that under some conditions sprouts may not persist to form permanent stems,[11/] others (16) have observed many trees in the 20- to 40-year age class that have originated as sprouts. On the other hand, black cottonwood is easily reproduced by cuttings (13). As early as 1893, reforestation was practiced rather extensively along the Willamette River lowlands in

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7/ Unpublished phenological data from the Pacific Northwest Forest and Range Expt. Sta., Portland, Oregon, and the Intermountain Forest and Range Expt. Sta., Ogden, Utah.

8/ See also: S. W. Allen. Silvical notes on *Populus trichocarpa* on the Klamath National Forest. U. S. Forest Service. 4 pp. (Typewritten) n. d.

9/ Ibid.

10/ Berry, *op. cit.*

11/ Allen, *op. cit.*

Oregon by cuttings. These cuttings, or "slips," as they were called, consisted of a section of cottonwood branch about 1 inch in diameter and 1 foot long with the bark and at least three buds left intact. The cuttings were placed vertically in the ground to a depth of about two-thirds their length and in rows spaced wide enough apart for cultivating with a horse-drawn cultivator. They remained in these beds for one year, while roots formed, and were outplanted in plantations during the following season. This method apparently worked very well for practical reforestation. Efforts at growing seedlings in the nursery in this early reforestation operation were abandoned because of the mortality caused by insects (14).

Most of the experience in cultivating black cottonwood comes from the Pacific Northwest in Washington and British Columbia. Recommendations by Beeman,[12/] Smith (16), and others (4), may be summarized as follows:

Cuttings should be made when the tree is dormant, and can be from 6 to 12 inches long, although longer cuttings may be desirable to facilitate later cultivation. Studies in British Columbia[13/] have shown that the position in the crown from which cuttings are taken has important bearing upon subsequent survival and growth. Cuttings of 1- and 2-year-old wood taken from the leaders and 1-year-old wood from primary side branches showed best growth and survival. Growth of cuttings from 2-year-old wood on side branches was much slower. Tests in the above study were made with cuttings taken from young trees, and differences in results may be more pronounced on cuttings from more mature trees. Best results have been obtained when the cuttings were rooted for one year in the nursery before field planting. Planting sets is not as good as planting rooted cuttings because the best that can be expected is that, in favorable soil only, sets will do as well as rooted cuttings (16).

Ground preparation is an important part in the success of plantings. Complete land clearing and intensive disking are recommended (16), but as a minimum practice cuttings can be planted in wide furrows made by throwing the lay to both sides.[14/] Land managers in British Columbia have practiced more intensive preparation by using a Caterpillar D-8 bulldozer and a 12-foot Rome disk with 30-inch blades. Natural reproduction, both vegetative and from seed, has been secured near Everett, Washington, when the area was scarified by bulldozer and branch segments were ground into the soil (16).

12/ Beeman, W. H. Report on hybrid poplar and native cottonwood experiments. 15 pp. (Typewritten) 1948.

13/ Smith, J. H. G. Reports on growth and yield and factors influencing cultivation of black cottonwood in British Columbia. (Information received through correspondence.) (Typewritten) 1955.

14/ Beeman, *op. cit.*

After planting, weeding is critical to insure good survival and growth. Grass and other vegetative competition must be held at a minimum for the first year. In British Columbia plantings, three hand hoeings and two tractor diskings had to be made during the first season. Under this practice, excellent first-year survival and growth were obtained (16). Where furrows are used two cultivations with a duckfoot cultivator or a sweep are recommended.[15]

Recommendations for spacing have varied considerably. One land manager in British Columbia uses 9-inch cuttings at a 12-foot by 12-foot spacing (16). Others have recommended closer spacings of 3 feet by 3 feet to 6 feet by 6 feet, or at least close enough to provide a closed canopy in 2 or 3 years.[16] However, on a large planting the wider spacing may be more practical because of lower cost and because it facilitates cultivation during the first season.

Spring is generally regarded as the best season for planting to avoid frost heaving, particularly on the heavier soils (16).

SEEDLING DEVELOPMENT

Establishment.--The seed shows a high percent of viability, and like that of other poplars it retains its germinative capacity for only a brief period under natural conditions (7, 8). However, cottonwood seed may be stored for 3 months to a year under refrigeration at low humidity (16). If the seed falls on a moist seedbed, high germination results. Wet river bars seem to offer the best medium; and moist, bare, humus or sandy soils such as those in streambanks and bottomlands are also good (6, 7).[17] On many drier sites seedlings are rare because the seedbed was dry at the time of seed dissemination.[18] When seedbed conditions are favorable, seedlings appear in great numbers, but they thin out naturally by the time they reach 5 years of age. This natural thinning is due to the suppression of the weaker seedlings by the more vigorous ones.[19]

Black cottonwood does not reproduce satisfactorily on logged-over land unless special measures are taken to provide the bare, moist seedbed required for initial establishment. Cottonwood occurs in the earliest stages of succession and tends to be replaced by more tolerant vegetation unless the required seedbed is provided by flooding or management practices (16).

15/ Ibid.

16/ Ibid.

17/ See also: Allen, op. cit.; Smith, op. cit.

18/ Berry, op. cit.

19/ Allen, op. cit.

Black cottonwood seedlings developing on mineral soil seedbed bared by flooding.

Early growth.--Black cottonwood makes very rapid juvenile growth; it exceeds most of its associates when growing on good moist sites. Dominant and codominant seedlings in the Pacific Northwest on Lady Island near Camas, Washington, attained a diameter of 6.7 inches at breast height and a total height of 48.5 feet in 9 years (15).

Exceptional growth of four selected individual trees in the Fraser Valley of British Columbia has been reported by Smith (16), as follows:

Age	D. b. h.	Total height
Years	Inches	Feet
7	7.0	45
17	18.6	95
17	22.4	85
27	32.5	120

On the Klamath National Forest in California, trees grew to diameters of 8 to 13 inches and heights of 30 to 50 feet in 20 to 27 years.[20] On rocky soils on the Modoc National Forest, also in California, trees up to 12 inches in diameter grew as much as 1 inch in diameter in 4 to 7 years, whereas the rate was reduced to 1 inch in 10 to 13 years thereafter.[21]

SAPLING STAGE TO MATURITY

Growth and yield.--Age of maturity in black cottonwood has not been determined accurately, but estimates range from 60 to 200 years (8, 14).[22] In the Willamette Valley, Oregon, it matures in about six decades or less, but on the Modoc National Forest, best development is reached in about 75 years (14).[23] On the better soils, sawlog-size trees develop in 20 to 40 years, and trees may be free of deterioration for as long as 100 to 150 years.[24] Growth was found to be uniformly rapid throughout the early life of trees in Inyo County, California, as illustrated by the following d.b.h. growth rates:

Period	Favorable site	Less favorable site
	Inches	Inches
First decade	5.5	2.5
Second decade	6.2	3.0
Third decade	5.3	2.7
Fourth decade	5.3	2.5
40-year total	22.3	10.2

A maximum diameter of 24 inches and a total height of 60 feet have been reported in Inyo County, California.[25]

On the Klamath National Forest, California, mature trees may reach 24 to 30 inches d.b.h. and 50 to 60 feet high.[26] In Glacier County, Montana, trees growing in groves on Babb loam and stony loam soils reached 12.8 inches in diameter and 45 feet in height in 82 years (11). The Montana trees were growing on the eastern extremity of the range of cottonwood bordering the grasslands and in a semiarid climate.

20/ Ibid.

21/ Wulff, J. V. *Populus trichocarpa*. U. S. Forest Service Silvical report. 4 pp. (Typewritten) 1912.

22/ See also: Allen, *op. cit.*; Wulff, *op. cit.*

23/ See also: Wulff, *op. cit.*

24/ Allen, *op. cit.*; Berry, *op. cit.*

25/ Berry, *op. cit.*

26/ Allen, *op. cit.*

Detailed studies of the yield of black cottonwood trees made in the Quesnel region (Fraser River) in British Columbia show that it grows well up to about 200 years. Culmination of periodic increment occurs beyond 200 years in age. However, a practical age of maturity for cottonwood growing in forest stands was determined to be 180 years. This figure was based on the age at which the distance from the ground level to the base of the crown (corresponding to merchantable length) reached its maximum.

In open mature stands the stem tapers only slightly, and is without branches for more than one-half its length; it then divides abruptly into large branches in the crown. In closed stands the crown is narrow, and persistent branches extend only rarely into the lower two-thirds of the bole (21). Tables 1 and 2 show basic growth and yield data for the middle Fraser region and Skeena River Valley in British Columbia.

Table 1.--Growth and yield characteristics for cottonwood in the Quesnel region, British Columbia[1/]

Total age (years)	Diameter at breast height	Height to base of crown	Gross volumes from stump height[2/] to a 10-inch top diameter	
	Inches	Feet	F.b.m.	Cu. ft.
80	15	52	235	44
90	17	56	295	54
100	19	60	365	64
110	20	62	450	76
120	22	64	545	89
130	23	67	655	105
140	25	69	780	123
150	26	70	935	146
160	28	71	1,110	173
170	29	72	1,310	200
180	31	73	1,520	225
190	32	73	1,720	250
200	33	73	1,920	273

1/ From Thomas and Podmore (21).

2/ Volumes according to British Columbia log rule and Smalian's formula.

Table 2.--Yield per acre of black cottonwood in Skeena River Valley, British Columbia[1/]

Age (years)	Net volume[2/] per acre	Mean annual increment per acre
	Board feet[3/]	Board feet
20	4,700	235
30	10,000	333
40	16,700	417
50	22,800	470
60	27,800	463
70	29,400	420

1/ Data collected in the Skeena River Valley of British Columbia by W. C. Phillips for the British Columbia Forest Service (16).

2/ Trees more than 11 inches d.b.h.

3/ British Columbia log rule.

Foresters in British Columbia recognize three site quality classes.[27/] They use the data shown in table 3, which have been checked by extensive sampling and found satisfactory for use there.

Table 3.--Black cottonwood site classification table[1/]

Age (years)	Site classes I		Site classes II		Site classes III	
	Total height	Diameter breast high	Total height	Diameter breast high	Total height	Diameter breast high
	Feet	Inches	Feet	Inches	Feet	Inches
5	25	--	21	--	16	--
10	47	5.7	43	4.8	33	3.6
15	72	9.5	59	7.1	46	5.9
20	95	12.5	79	9.0	59	6.5
25	111	16.0	92	12.0	72	8.0
30	118	20.0	102	14.5	82	10.5
35	125	22.0	108	17.0	89	12.0

1/ Data from Hesmer, Das Papelbuch, cited by Smith (16, 17).

27/ See p. 5 above.

Smith (16, 17) gives the following instructions for collecting data for site classification: "The height or d.b.h. and age of at least two trees must be measured for each spot to be evaluated. The largest and tallest trees should be measured. One year should be added to the age of trees bored at a height of 1 foot. Total height and age are more reliable indicators of site quality than diameter breast high and total age. The number of plots required to classify site quality depends upon the area and uniformity of tree distribution and size in a given stand" (20).

Kennedy's recent study[28/] shows that longer wood fibers are associated with faster rates of growth; thus faster growing cottonwoods produce generally better quality material for both veneer and pulpwood than do slower growing trees.

Reaction to competition.--Black cottonwood is the most shade-intolerant of its associates and is classified as being very intolerant (1). Because of this high degree of intolerance it can remain in the stand or in mixture with other species only so long as it occupies a dominant position. Where it cannot maintain dominance it is soon suppressed and replaced by other species. However, its rapid juvenile growth rate, exceeding that of most of its associates, helps it to maintain a favorable position in stands (7, 8, 19).[29/] Black cottonwood occurs in the earliest stages of ecological succession and tends to be replaced by more tolerant grass, trees, or shrubs (21).

INJURIOUS AGENCIES

Weather and related agents.--Certain climatic factors, while they may not be distinctly limiting, do cause damage to the species. Since black cottonwood is among the first species to start growing and flowering in the spring, late frosts frequently injure it.[30/] Many cottonwoods were killed outright or killed back from 2 to 20 feet in height by a late fall frost in British Columbia in November 1955. Frost cracking of the boles further damages cottonwood for some uses and provides entrance for decay fungi (16). Wind breakage is an important type of weather damage.[31/] Wind not only breaks off trees and reduces size of the crown through branch removal, but the resulting scars form avenues of entrance for wood-destroying fungi. A serious form of wind damage has been reported by foresters in Scotland. Because of their comparatively rapid growth, black cottonwood trees often project above the protection of surrounding trees. After they reach 80 feet or more in height, the wind

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28/ R. W. Kennedy, Faculty of Forestry, University of British Columbia. Cited by Smith (16).

29/ See also: Wulff, op cit.

30/ Berry, op. cit.

31/ U. S. Forest Service, op. cit.

frequently breaks off the upper third of the tree (2). In areas of heavy snowfall, saplings have been reported badly snow bent.32/ Sleet storms may also cause considerable breakage. The "silver thaw" has been reported to cause severe damage around Chilliwack, British Columbia, as frequently as once in 20 years (16). Black cottonwood is highly susceptible to fire damage, and even light burns can cause considerable injury.33/

Erosion may be a serious problem in stands located on the flood plains of large rivers where many of the best stands occur. Periodic flooding is not always detrimental; in fact it sometimes promotes growth. However, in some rivers islands tend to be eroded upstream and built up downstream. The total change in land area may be insignificant in such cases, but instability of the soil may pose serious problems in cultivating this species (16).

Insects.--Several insects attack this bole. Some of them have been reported from only limited portions of the tree's range, but others are more widely distributed. Oystershell scale (*Lepidosophes ulmi*) is especially destructive to aspen, cottonwood, and willows, and is distributed throughout the United States. This insect frequently kills twigs and branches and sometimes the whole tree. Two defoliators are known to attack black cottonwood in parts of its range. The satin moth (*Stilpnotia salicis*), introduced from Europe, was first reported in British Columbia and Massachusetts in 1920. It is now considered firmly established in Oregon and Washington, and feeds on many *Populus* species, including black cottonwood. The cottonwood sawfly (*Pteronidea* sp.) also feeds on black cottonwood leaves. Its reported distribution is limited to northern Idaho where it occurs commonly. A small cambium miner (*Lespeyresia populana*) is known to breed in the bark of black cottonwood in Montana. Several insects among the flat-headed and round-headed borers and the ambrosia beetles are known to attack the species, but these insects have economic importance as wood destroyers rather than tree killers (5, 9).

Disease.--Black cottonwood is subject to several diseases. The cytospora canker (*Valsa sordida*) is widespread among the poplars, including black cottonwood, under forest conditions. However, it is most prevalent in stands injured by fire or located on unfavorable sites; its occurrence is highly correlated with the vigor of the tree. This canker is primarily a disease of young trees and causes most serious damage on cuttings in nurseries and plantations (4).

The wood of this species is attacked by several wood-decaying fungi. In the middle Fraser region, British Columbia, 70 species of fungi have been found to cause decay in black cottonwoods. However, only six cause significant loss in living trees, and only two of these (*Polyporus delectans* and *Philiota destruens*) cause about 92 percent of the loss (21). As a group, the cottonwoods have been classed by the Forest Products Laboratory as nondurable with respect to decay.

32/ Wulff, *op. cit.*

33/ Allen, *op. cit.*

Many investigators have rated black cottonwood, outside of its native habitat, as highly susceptible to disease. Its use for commercial planting in Europe has been largely discontinued because the species has suffered so severely from attacks of bacterial canker (16).

SPECIAL FEATURES

Evidence indicates that trees of the cottonwood family grew in Greenland during the Cretaceous age. Some old species have disappeared, but others have presumably survived until the present without great change. Their characteristic great vitality has been credited as the factor that enabled this survival from former geological epochs (7).

RACES

Black cottonwood shows considerable ecotypic variation throughout its range both in latitude and altitude. Pauley and Perry (12) studied variations in photoperiodic response in black cottonwood and several other poplars. Their studies showed that the time of cessation of height growth on specimens collected from various parts of the tree's range, when tested in plots in the vicinity of Boston, Massachusetts, under uniform environmental conditions varied inversely with the latitude of the plant's origin. In other words, when grown under similar habitat conditions the trees of northern origin ceased height growth earlier in the season than those of southern origin. Pauley and Perry also found that in trees from a uniform day-length zone the date at which height growth ceased was directly correlated with the length of the frost-free season prevailing in the original habitat of the specimen.

They concluded that adaptation of *Populus* species to various habitats differing in length of frost-free season is effected by a genetic mechanism that controls the duration of seasonal period of growth. The photoperiod or length of day serves as a timing device for this mechanism.

On the basis of the above study Perry and Pauley made certain suggestions on seed source:

1. Seed from northern long-day races planted in southern latitudes having a long growing season are likely to produce trees that will stop height growth early in the season, and thereby become dwarfed.

2. Trees produced from seed of trees growing in a region having a short growing season, such as high altitude habitats of mountainous areas in the southern parts of the range, may be expected to react the same as northern long-day types. Seed collected in such habitats, therefore, are not recommended for use in the same latitude at lower elevations or at more southerly latitudes.

3. Seed from trees in a long growing season habitat in any particular latitude should be avoided for use in areas having shorter growing seasons either at higher elevations in the same latitude or at more northerly latitudes. Trees from such seed are susceptible to early autumn frost damage in the latter habitats.

POPLAR HYBRIDS

Several studies show that the use of some hybrid poplars has distinct advantages over native black cottonwood in growth and yield.[34] Extensive testing (48 different hybrids) by the Soil Conservation Service at Bellingham, Washington, shows that some hybrids considerably exceed the growth of native black cottonwood. The following table by Beeman shows the quantitative superiority of the hybrids in these tests:

Table 4.--Comparison of growth of hybrid poplars and native black cottonwood after fifth growing season

Item	Survival	Height	Diameter
	Percent	Feet	Inches
Hybrid, average	92.8	24.6	4.2
Native black cottonwood, average	91.2	17.3	3.3
Best pulpwood-type hybrid	100.0	31.2	4.9
Best native check	92.0	24.7	4.1

Growth of the selected hybrids was 42 percent greater in height and 27 percent greater in diameter than the best growth of the black cottonwood. Also, the hybrids apparently were immune to a leaf roller that attacked the black cottonwood consistently.[35] Black cottonwood plantations on some lands in Washington are producing pulpwood at the rate of 1.6 cords per acre per year. By contrast, hybrid plots have indicated possibilities of a total harvest of 44 cords per acre at 18 years, or 2.4 cords per acre per year.[36]

34/ Beeman, op. cit.

35/ Ibid.

36/ Ibid.

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FOREST INSECT CONDITIONS in the INTERMOUNTAIN & NORTHERN ROCKY MOUNTAIN STATES DURING 1958

INTERMOUNTAIN FOREST & RANGE EXPERIMENT STATION
REED W. BAILEY, DIRECTOR

FOREST SERVICE
U. S. DEPARTMENT OF AGRICULTURE

OGDEN, UTAH MARCH 1959

Misc. Pub. No. 18 March 1959

FOREST INSECT CONDITIONS IN THE INTERMOUNTAIN AND NORTHERN ROCKY MOUNTAIN STATES DURING 1958

By

Division of Forest Insect Research

INTERMOUNTAIN FOREST AND RANGE EXPERIMENT STATION
Forest Service
U. S. Department of Agriculture
Ogden, Utah
Reed W. Bailey, Director

COVER PHOTO

Helicopter discharging survey crewman on 10,100 foot ridge in lodgepole pine area. Use of helicopter permitted survey activity before roads were in condition for travel.

FOREST INSECT CONDITIONS IN THE INTERMOUNTAIN AND NORTHERN ROCKY MOUNTAIN STATES DURING 1958

Entomologists of the Intermountain Forest and Range Experiment Station collected and coordinated information gained during the annual forest insect survey of 1958. Participation in the program by personnel in other Federal and State land-managing agencies, forest industries, and interested private landowners is gratefully acknowledged. Cooperative action resulted in more effective coverage than would otherwise have been possible.

With aircraft based at Missoula, Boise, and Ogden, a program of aerial observation of forested areas was carried on. It was not possible to survey all forested areas during 1958 but it is doubtful that any serious infestation escaped detection. Ground surveys were performed wherever observation or reports indicated that insect populations were reaching serious levels.

In general, insect outbreaks in the Intermountain States showed a decided increase, notably because of increased activity by mountain pine beetle and Engelmann spruce beetle. Conditions in the northern Rocky Mountain States did not worsen noticeably over those reported for 1957.

Numerous forest insect situations in the area covered by the surveys are serious. Control action is under way against widely scattered outbreaks throughout the area. This report presents the status of both major and less important forest insects for 1958.

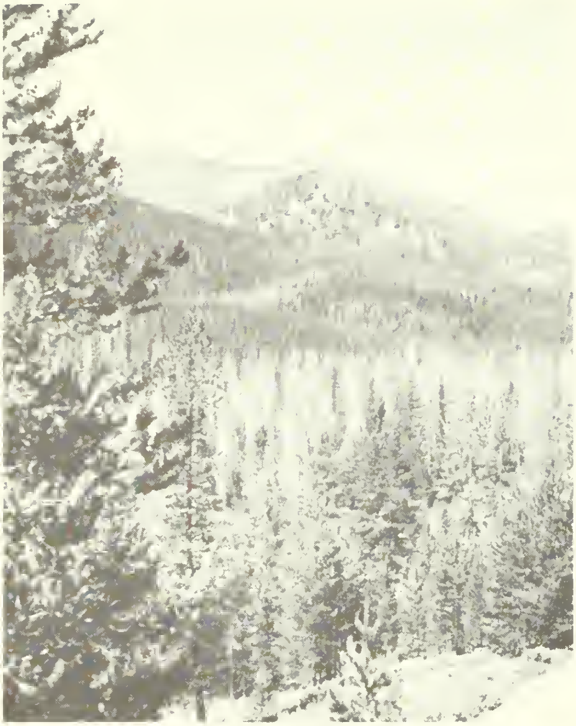
BARK BEETLES

MOUNTAIN PINE BEETLE

Dendroctonus monticolae Hopk.

During 1956 populations of mountain pine beetle in lodgepole pine were increasing in parts of Utah, southern Idaho, and western Wyoming. Surveys in 1957 showed continuing evidence of this increase. Records obtained in 1958 cause considerable concern over the upward trend that was obvious from aerial and ground observations.

An extensive outbreak on the Wasatch National Forest in Utah continues. This particular epidemic is not new but has fluctuated at rather high levels since 1950. During the past few years it has increased areawise as well as in intensity. A large-scale control program was started in 1958 to prevent further spread and reduce populations as progress is made from the edges into the main body of infestations. As many as 89,000 trees may be currently infested. On the Ashley National Forest, control efforts continue in centers first reported last year.



Lodgepole pine snags, result of mountain pine beetle attack

Mountain pine beetle infestations on Grand Teton National Park in Wyoming and on the adjoining Teton National Forest still threaten extensive lodgepole pine stands. Control projects in infestation centers have reduced populations of beetles, but new groups of infested trees are found in the same general areas. The most recent discovery was of two major infested areas on the Targhee National Forest that are in the general area of the large-scale Targhee-Teton outbreak of the late 1940's. The Sawtooth National Forest in southern Idaho is also the site of an outbreak of mountain pine beetle that has developed in severity for several years. The well-defined trends toward increasing populations in Utah, western Wyoming, and southern Idaho demand increased vigilance in lodgepole stands. In Montana, the mountain pine beetle in lodgepole persists in Glacier National Park in several stands, but the general level of the outbreaks decreased somewhat between 1957 and 1958.

The mountain pine beetle in old-growth white pine stands in northern Idaho continues to kill significant volumes each year. Biological evaluations and past records indicate that populations kill between 1 and 2 percent of the numbers of trees in these old-growth stands.

Treatment of a mountain pine beetle infestation in second-growth ponderosa pine on the north shore of Lake Tahoe in Nevada was undertaken in 1958. This infestation has been present and recorded for the past few years. By salvage-logging and the cutting and burning of unmerchantable material, this infestation has been reduced. The operation was not complete and additional infested trees were located late in the season.

A small but threatening outbreak of mountain pine beetle in approximately 150 trees was located in second-growth ponderosa pine on the Boise National Forest in Idaho. Since mountain pine beetle can be a serious pest in these second-growth stands, immediate steps were taken to fell and destroy the infested trees.

ENGELMANN SPRUCE BEETLE

Dendroctonus engelmanni Hopk.

Remnants of the 1952 destructive outbreak of the Engelmann spruce beetle persist in some of the national forests of Montana, particularly in the Flathead and Kootenai Forests. Logging is directed into these areas to remove infested material and further reduce populations.

An infestation of spruce beetle, which apparently developed in windfelled spruce, was discovered during 1958 in the Beartooth Primitive Area of the Custer National Forest in Montana involving a gross of 4,500 acres.

Extent of spruce beetle damage revealed by removal of dead and infested trees

A striking increase in Engelmann spruce beetle occurred during 1958 in Utah. The most serious epidemic covers about 100 square miles (gross area) of spruce type where the Wasatch, Ashley, and Uinta National Forests join. It was estimated that more than 55,000 trees were infested when the area was first surveyed. Control action was started through logging of infested stems plus treatment of infested slash and stumps.

Another serious outbreak developed on the Manti-LaSal National Forest and adjoining State and private lands in southeastern Utah. The number of trees was estimated at 13,500. Control action was taken immediately.

A lesser outbreak involving about 3,000 infested trees was discovered on the Dixie National Forest. The infestation was in a sale area and most of the trees were either logged or treated during the season.

A relatively small, but intense, outbreak developed in 1958 on the Payette National Forest in Idaho. This outbreak threatens considerable spruce in the area.

The outbreak on the Bridger National Forest in Wyoming that has been active for the past 3 years continues. Control work has reduced the populations but in some portions of the area the species is still killing considerable volumes of spruce.

DOUGLAS-FIR BEETLE

Dendroctonus pseudotsugae Hopk.

For the past several years the Douglas-fir beetle has been at a relatively low level. During 1958 a distinct upward trend was noted in Douglas-fir stands in the northern Rocky Mountain area and in the Intermountain States. In the northern area most outbreaks are in scattered locations in northeastern Washington, northern Idaho, and Montana west of the Continental Divide. Two outbreaks have been reported east of the divide on the Gallatin National Forest, Montana, and in Yellowstone National Park, Wyoming. Two fairly large areas containing approximately 600 trees each were located on the Sawtooth and Payette National Forests in Idaho. An older outbreak on the Dixie National Forest in southern Utah continues at a high level.

WESTERN PINE BEETLE

Dendroctonus brevicomis Lec.

Mortality of ponderosa pine caused by western pine beetle remains at a low endemic level. Most infested trees occur singly and widely scattered throughout old-growth pine stands.

LODGEPOLE PINE BEETLE

Dendroctonus murrayanae Hopk.

Small outbreaks of the lodgepole pine beetle have been reported in lodgepole pine stands in the Gallatin National Forest in Montana. Beetle attacks appear to be confined to trees with previous top injury caused by porcupine feeding and bole attacks of an undetermined pitch moth.

BLACK HILLS BEETLE

Dendroctonus ponderosae Hopk.

An outbreak of Black Hills beetle that has been active on the Dixie National Forest and Bryce Canyon National Park in southern Utah since 1950 shows a downward trend. Control projects have been carried out each year, yet new centers have appeared in other areas. In 1958 surveys indicated a decided reduction in numbers of infested trees with the exception of one area.

SOUTHWESTERN PINE BEETLE

Dendroctonus barberi Hopk.

The southwestern pine beetle continues to kill ponderosa pine on the heavily used recreational areas of Charleston Mountain near Las Vegas, Nevada. The rate of loss has been reduced by maintenance control throughout the active season, but it appears that this treatment will be necessary as long as the present trend of the infestation continues.

DEFOLIATORS

SPRUCE BUDWORM

Choristoneura fumiferana (Clem.)

The spruce budworm continues to be a serious defoliator in Montana, Wyoming, and Idaho. The net acreage of infestation in the northern Rocky Mountain area is approximately 2.9 million acres, part of which is in Yellowstone National Park. In southern Idaho about 820,000 acres show noticeable defoliation. While the infestations in southern Idaho have increased areawise each year since 1952, surveys in 1958 showed that for the first year there was no general increase in severity of damage. The most serious conditions exist on the Salmon National Forest bordering Montana.

BLACK-HEADED BUDWORM

Acleris variana (Fern.)

Fairly widespread infestations of black-headed budworm, reported in 1956 and 1957, subsided in 1958 to a single infestation on the Kootenai National Forest in Montana. Here damage to western hemlock host stands, as observed during aerial survey, was hardly visible. The 1958 Kootenai infestation covers approximately 1,500 acres. Known infestations of this budworm in 1956 and 1957, mostly on the Kootenai Forest, Montana, and the Kaniksu National Forest, Idaho, subsided from natural causes late in 1957.

Approximately 50,000 acres of lightly defoliated alpine fir were located this year. This defoliation occurred in the high altitude ridge tops and was caused by black-headed budworm.

PINE-FEEDING BUDWORM

Choristoneura lambertianae (Busck)

A small outbreak of the pine-feeding budworm was reported in 1957 from lodgepole stands near Missoula, Montana. Populations of the budworm were plentiful enough in 1958 for collection purposes, but the damage to the foliage was not significant. Although this infestation is the only extensive one in the northern Rocky Mountains, individual specimens of this insect were collected in 1958 from *Pinus ponderosa* var. *scopulorum* Engelm. from the Long Pines section of the Custer National Forest on the Montana-South Dakota State line; also from ponderosa pine on the Helena National Forest, Montana.

PINE BUTTERFLY

Neophasia menapia (F. & F.)

Each year since the spray operation in 1954 to control pine butterfly, special attention has been given to relative abundance of adult pine butterflies in ponderosa stands in Idaho. During aerial surveys on the Salmon National Forest, sufficient numbers of adults were seen to warrant egg examinations. These examinations showed that approximately 50,000 acres of ponderosa pine were supporting a noticeable population. Egg surveys revealed about seven eggs per twig within the center of the area to less than one along its edges. An average of nine or more eggs during sampling is considered an indication of epidemic conditions. Defoliation observed was light, but occasional heavily defoliated trees were seen. There appeared to be a fairly high population of *Theronia atalantae* (Poda.), a parasite of the pine butterfly, for this stage of development of an outbreak.

Ponderosa pine defoliated by pine butterfly

DOUGLAS-FIR TUSSOCK MOTH

Hemerocampa pseudotsugata McD.

During 1957, planning was started for an aerial spray project to control Douglas-fir tussock moth in Owyhee County in southern Idaho. Observations and collections late in the season indicated that a virus disease was quite common within the population. It was then decided to cancel all plans for spraying. Surveys in 1958 revealed that the virus disease had practically eliminated the outbreak.

RUSTY TUSSOCK MOTH

Orgyia (*Notolophus*) *antiqua* (L.)

An epidemic of rusty tussock moth was reported in 1958 on 1,500 acres of shrub vegetation near West Yellowstone, Montana. Some subalpine fir foliage also showed evidence of feeding in this area. A study of moth cocoons from the area showed that there was a ratio of one 1958 egg mass to nine 1957 or older egg masses. This indicates that the infestation has declined rapidly this year.

TUSSOCK MOTH

A tussock moth, in epidemic numbers, was found feeding on bitterbrush, willow, wild rose, and desert peach on the foothill ranges between Carson City and Reno, Nevada. By the end of the active feeding period (last of June) the valuable bitterbrush was nearly 100 percent defoliated over the 40 acres inspected. The exact extent of the outbreak was not determined, but probably much of the foothill range between Carson City and Reno supported epidemic populations of tussock moth. Quite possibly other bitterbrush ranges in western Nevada and eastern California were subjected to defoliation by this tussock moth.

Severe defoliation of bitterbrush can be very detrimental since it removes the palatable forage that supports large numbers of deer. Repeated defoliation may eventually cause mortality to some of the browse plants. To date the species of tussock moth involved in this range problem has not been determined.

LODGEPOLE PINE NEEDLE MINER

Recurvaria milleri Busck

The lodgepole needle miner is now in epidemic numbers throughout most of the Cassia Division of the Sawtooth National Forest in Idaho, and a small infestation (about 1,500 acres) has appeared west of Gerrit in the center of the extensive lodgepole pine stands of the Targhee National Forest. The previous outbreak that died out in 1953 covered much of the Sawtooth, Caribou, and Targhee National Forests.

PINE TIP MOTH

Rhyacionia sp.

Severe damage from a pine tip moth caused considerable damage to natural reproduction of ponderosa pine, *Pinus ponderosa* var. *scopulorum* Engelm., on the Long Pines section of the Custer National Forest, Montana. Similar infestations have also been reported in other parts of the Sioux Division of the Forest. The damage is heavy in spots and covers considerable area. The infestation has apparently persisted for several years, and similar infestations were reported from this area as early as 1936. Efforts this season to obtain living specimens of the tip moth for determination were unsuccessful. In 1936, however, the specimens collected from this area were determined to be *R. frustrana bushnelli* (Busk) and *R. neomexicana* (Dyar).

Reproduction in the infested area is very dense. It has become considerably deformed and stunted from recent feeding by tip moth. Some mortality of young trees appears to be imminent if the infestation continues unchecked.

Associated with the *Rhyacionia* infestation are minor populations of three other insects: *Choristoneura lambertianae* (Busck), a gelechiid, and the jack pine needle miner, *Zelleria haimbachi* Busck.

BARK MOTH OF DOUGLAS-FIR

Laspeyresia fletcherana Kearf.

A relatively new pest of Douglas-fir reproduction was reported by the Missoula Laboratory. Larvae of a moth caused some damage to Douglas-fir Christmas tree stock by boring in the bark of boles and limbs. Boring does not penetrate the cambium layer of any except the smallest seedlings. Seedlings as small as 15 inches in height have been attacked. In small trees the insect has caused some top killing in the infestation area on the Rexford Ranger District in the Kootenai National Forest, Montana. Except for the possibility of damage to small seedlings, the pest is not believed to be economically important.

TENT CATERPILLARS

Populations of the forest tent caterpillar, Malacosoma disstria Hbn., are prevalent in the northern Rockies for the first time in four seasons and appear to be increasing in Missoula County, Montana. Scattered infestations of Great Basin tent caterpillar, M. fragilis Stretch, were observed occasionally west of the Continental Divide in Montana but appear to be more numerous east of the divide on a variety of shrubs, mainly Prunus, but also Rosa, Amelanchier, and rarely Ribes. Caterpillar populations in the vicinity of Bozeman, Montana, were strongly parasitized by ichneumonids which pupated within the skin of the half-grown host; most other caterpillars died, possibly of disease, before pupating. Tent caterpillars have not been collected recently in Montana in Populus, Salix, or Acer.

Numerous dead larvae of tent caterpillar on defoliated branches showed symptoms of disease

Tent caterpillars were abundant throughout most of the Intermountain area in 1958. One of the more serious outbreaks occurred on the Cache National Forest along the Wasatch front facing the heavily populated Salt Lake valley. Mountain maple, chokecherry, and several browse plants were the most heavily attacked. A virus disease attacked the mature larvae in this outbreak and succeeded in killing a very high percentage of the population before pupation occurred. Some local centers may develop next year, but they probably will be controlled by the virus disease. The forest tent caterpillar, Malacosoma disstria Hbn., was most prevalent, but the Great Basin tent caterpillar, M. fragilis Stretch was also present.

LARCH CASEBEARER

Coleophora laricella (Hbn.)

A severe infestation of this insect was discovered in 1957 in the vicinity of St. Maries, Idaho. This infestation was the first recorded western appearance of this forest defoliator. At that time visible defoliation extended over an area of 15,000 acres of western larch stands. A detection survey in 1958 showed that the casebearer is now present over 110 square miles in northern Idaho and northeastern Washington. Although no visible defoliation was observed outside the 15,000 acres reported in 1957, the casebearer was found in small numbers as far north as Sandpoint, Idaho, and Chewelah, Washington. No southern expansion of the infestation was found beyond Clarkia, Idaho.

LARCH BUDMOTH

Zeiraphera griseana (Hbn.)

A 3-year-old outbreak of larch budmoth ended in 1958. No visible defoliation by this insect could be detected during aerial surveys, and ground examinations showed that the budmoth has practically disappeared in all of the areas that had been heavily infested in 1957.

LARCH LOOPER

Semiothisa sexmaculata (Pack.)

Since 1955 this geometrid has been the most widespread defoliator of western larch in the northern Rockies. However, with the exception of a few small areas, looper populations have remained at a low level. In 1958 the insect still could be found throughout the region, but only in small numbers even in the few localities where measurable populations were observed in 1957.

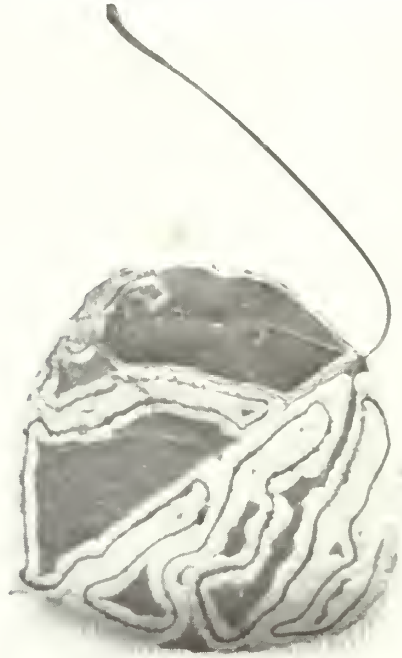
LARCH SAWFLIES

Pristiphora erichsonii (Hartig)

In July an infestation of the larch sawfly was discovered in Missoula County, Montana. This is the first time this species has been observed in the northern Rocky Mountains since 1944. Visible defoliation extended over several square miles of scattered sapling- and pole-sized western larch stands near the junction of the Clearwater and Blackfoot Rivers. Heavy defoliation was observed in individual drainages, where trees were completely stripped of needles. By August 1, most current year's feeding was completed and the larvae were pupating. Counts of pupae varied from 40 to 60 per square foot of duff in an area of heavy defoliation. For the past several years two sawflies--the two-lined (*Anoplonyx occidens* Ross) and the western *A. laricivorus* Roh. & Midd.)--frequently have been found associated with the larch looper, *Semiothisa sexmaculata* (Pack.), in larch stands of western Montana, northern Idaho, and northeastern Washington. Field observations indicate that both sawfly species have two generations per year in this region, but their numbers in 1958 were too few to cause visible defoliation of larch.

ASPEN LEAF MINER
Phyllocnistis populiella Chamb.

The aspen leaf miner has been in epidemic status for about 10 years on four national forests in western Wyoming and southeastern Idaho. The infestation is still very active, and this year, as in the past, nearly 100 percent of the foliage of all aspen trees within the infestation was heavily mined. On the Teton National Forest much of the foliage has been stunted by continuous feeding. Many patches of dead aspen, ranging in size up to 10 acres, are scattered throughout the infestation and it is now felt that most of the mortality resulted from repeated heavy feeding by the leaf miner.



Typical leaf damage by larvae of aspen leaf miner

SUCKING INSECTS

WHITE PINE APHID
Pineus coloradensis Gill.

In 1958 a survey was begun to determine the extent to which an aphid, tentatively determined as Pineus coloradensis Gill., is associated with crown deterioration of western white pine in the Inland Empire. For some years loss of 2- and 3-year-old needles in stands throughout the range of white pine has been serious. The deterioration has thus far been undetermined. In several areas mortality of trees in the younger age classes has become increasingly apparent. In 1958 this aphid was found widely dispersed throughout the range of white pine. An attempt has been made to determine whether the aphid is associated with crown deterioration, but this study has not progressed beyond the initial explorations.

PINE NEEDLE SCALE

Phenacaspis pinifoliae (Fitch)

Infestations of the pine needle scale were unusually abundant throughout the northern Rocky Mountain region on ornamental evergreens during 1958. The infestations were unusually widespread, and although plants were heavily infested, they did not appear to be serious.

MEALYBUG

An infestation of mealybug approximately 6,000 acres in extent was found on the Payette National Forest on true firs, white bark pine, spruce, and lodgepole pine. Present damage does not appear serious.

SPRUCE MEALYBUG

Puto sp.

The spruce mealybug infestation covering approximately 60,000 acres of spruce in southern Utah is still very active. The area of infestation did not increase in 1958. Continued heavy feeding within the infestation is rapidly reducing vigor of the mature spruce and is causing some deformity in the younger trees.

SPRUCE SPIDER MITE

Oligonychus ununguis (Jacobi)

Infestations of spruce spider mite persist in several national forests east of the Continental Divide in Montana. Surveys in 1958 showed that mite populations remained heaviest in those areas sprayed for budworm control in 1956-1957. Without exception, mite populations were insignificant in areas that had not been sprayed. Examination in areas showing heavy foliar injury in 1957 indicated that mite populations were rapidly declining and foliar injury in 1958 was greatly reduced.

SILVICS *of* LODGEPOLE PINE

Botanical range of lodgepole pine.

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SILVICS OF LODGEPOLE PINE

By

David Tackle
Forester

INTERMOUNTAIN FOREST AND RANGE EXPERIMENT STATION
Forest Service
U. S. Department of Agriculture
Ogden, Utah
Reed W. Bailey, Director

FOREWORD

The SILVICS OF LODGEPOLE PINE is the fourth publication in the series of seven silvics manuals being published by the Intermountain Forest and Range Experiment Station as part of a larger project sponsored by the U.S. Forest Service. Forest Service Experiment Stations over the Nation are issuing similar bulletins on many important North American tree species. Eventually a single publication that will include the entire series will be issued by the U.S. Forest Service.

Information in this publication is based on selected references and unpublished research data through 1957. The author will appreciate having any omissions or apparent misinterpretations called to his attention.

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SILVICS OF LODGEPOLE PINE

By

David Tackle[1/]

Lodgepole pine (Pinus contorta) (38)[2/] has a wide geographic range. It extends from Alaska and interior Yukon Territory south to northern Baja California and east to the Black Hills of South Dakota. The northern limit is at about 64° N. latitude on the divide between the Klondike and McQuesten Rivers; the southern limit is at about 31° N. latitude in the northern part of Sierra San Pedro Martir in Baja California (58).

Some taxonomists distinguish two varieties of this pine: Pinus contorta var. contorta, a coastal form, and Pinus contorta var. latifolia, an inland or mountain form. The coastal form is the low, scrubby tree of the Pacific coast from southeastern Alaska to northern California, while the inland form is the taller tree of the mountains from Yukon southeast to Colorado (38). The reproductive organs of both forms are practically identical (29) and for a long time morphological differences were considered unreliable. Variations were described as largely environmental (18). Recently a detailed study (14) of the geographic variation of this pine has shed new light on its taxonomy, and it has been proposed that the species be divided into four subspecies. This taxonomic division is described later under "Races and Hybrids."

The interior form has the greater commercial importance today, especially in Montana, Oregon, Idaho, Utah, Wyoming, and Colorado, and in British Columbia and Alberta, Canada.

HABITAT CONDITIONS

CLIMATIC

It is difficult to generalize about the climate in which lodgepole pine grows. The interior form usually is found in a cool, relatively dry climate having a wide seasonal range in temperature; the coastal form grows best in rather cool, moist zones having a relatively narrow seasonal range in temperature.

In most areas where the interior form grows, summers are fairly dry and precipitation is likely to be deficient for short periods during the growing season. Best development occurs where annual precipitation is 21 inches or

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1/ Forester, Intermountain Forest and Range Experiment Station, Forest Service, U. S. Dept. of Agr.; stationed at research center, Missoula, Montana.

2/ Underlined numbers in parentheses refer to Literature Cited.

more, but extensive stands are found where precipitation is only 18 inches (39) Annual snowfall generally varies from 11 to 120 inches, but may reach as much as 250 inches or more and lie on the ground until late spring (41). The growing season is generally short (60 to 100 days), and frosts may occur every month in the year. Average July temperatures generally are between 55° and 63° F. Temperature extremes of about 100° F. and -55° F. occur for short periods (39).

EDAPHIC

Lodgepole pine is not exacting in its soil requirements and grows on a wide variety of soils. The interior form does well on moderately acid, sandy, or gravelly loams that are moist, light, and well drained (29).

In the region where lodgepole pine has its greatest commercial importance, good stands are found on soils of granitic, shale, or sandstone origin. Extensive stands also occur on soils derived from coarse-grained lavas. In the United States, soils derived from limestone or fine-grained igneous rocks generally do not support good stands (4). The former are too dry, and the latter break down into clays that are too poorly drained (12). However, in Alberta, Canada, stands of medium to good productivity commonly occur on well-drained, calcareous tills having a silty loam or clay loam texture.[3/]

In the Cascade Mountains of Oregon and Washington and the Sierra Nevada in California, lodgepole pine occurs mainly on wet flats and poorly drained soils. In the Sierra Nevada the incidence of small lodgepole pine stands within ponderosa pine (Pinus ponderosa) stands is determined by the presence of a clay pan impervious to moisture under the lodgepole (33). Similarly, in eastern Oregon, soils with underlying hardpan, which helps retain soil moisture in the root zone, support lodgepole pine to the exclusion of ponderosa pine (49).

In central Oregon lodgepole pine occurs mainly on level sites having a relatively high water table or on poorly drained soils. However, at elevations above the 5,000- to 6,000-foot zone, it occurs on sites that are well or excessively well drained. In these areas the pattern of occurrence is believed to be created by past fires.[4/]

In the Blue Mountains of northeastern Oregon and southeastern Washington, occurrence is nearly always upon volcanic ash (pumicite) soils or alluvial material overlying residual basaltic soils at elevations between 3,000 and

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3/ Written communication from Canada Department of Northern Affairs and National Resources, Calgary, Alberta, dated October 15, 1956.

4/ Written communication from Pacific Northwest Forest and Range Experiment Station, Portland, Oregon, dated October 23, 1956.

7,000 feet (65). These soils are much deeper than the residual soils of the area and afford the greater moisture supply necessary for aggressive lodgepole pine growth.[5]

Pure scrubby stands of the coastal form are found in peat bogs or muskegs in southeastern Alaska and British Columbia and in the Puget Sound Basin of western Washington. Similar stands occur farther south on dry sandy and gravelly sites near the Pacific Ocean (29).

PHYSIOGRAPHIC

The altitudinal range of lodgepole pine extends from sea level up to 11,500 feet. The coastal form is restricted to elevations from near sea level up to about 2,000 feet. The inland form occurs from 1,500 feet to 11,500 feet elevation.

In the more southerly latitudes lodgepole pine grows at progressively higher elevations. In Yukon Territory, at the northern part of its range, lodgepole is found between 1,500 and 3,000 feet elevation; farther south in Montana, east of the Continental Divide, between 4,500 and 9,000 feet; in northern Wyoming between 6,000 and 10,500 feet; and in southern Wyoming and Colorado between 7,000 and 11,500 feet.

Lodgepole pine generally grows in mountainous regions, but may be found under a great variety of topographic conditions. It grows especially well on gentle slopes and in basins, but many good stands are found on rough and rocky terrain (59). On steep slopes and ridges it grows on bare gravel (39). Northern and eastern aspects are favored over western aspects. Southern aspects are least favorable except in sheltered locations.

BIOTIC

Lodgepole pine is a major timber species in the Canadian life zone (43) of both the Cascade-Sierra and Rocky Mountain ranges. The type is part of the forests of the interior middle elevations and is considered pure when there are no significant amounts (more than 20 percent) of either western white pine (*Pinus monticola*) or ponderosa pine (57). However, minor numbers of several species may be present. The coastal form is not recognized as a distinct type.

This pine is represented in 11 other cover types of western North America (57). At high elevations in the mountains it is a minor component in the Engelmann spruce (*Picea engelmannii*)--subalpine fir (*Abies lasiocarpa*), red fir (*A. magnifica*), and whitebark pine (*Pinus albicaulis*) types. At middle elevations in the interior it is a minor component of the following types: interior Douglas-fir (*Pseudotsuga menziesii* var. *glauca*), larch (*Larix occidentalis*)--Douglas-fir, ponderosa pine--larch--Douglas-fir, western white pine, Rocky

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5/ Ibid.

Mountain juniper (Juniperus scopulorum), and aspen (Populus tremuloides). It is also found in the western juniper (J. occidentalis) type, which occurs at low elevations in the interior, and in the Jeffrey pine (Pinus jeffreyi) type.

Although dense lodgepole pine forests have a dearth of minor flora, certain shrubs and occasionally herbs typify the stands when they are not heavily overstocked and where they do not occur in a transition zone between other timber types. Following are lists of these plants in the principal localities where lodgepole pine can be defined as a true cover type:

a. Cascade Range in Washington and Oregon--Xerophyllum tenax, Pachistima myrsinites, Vaccinium spp., Arctostaphylos nevadaensis, Amelanchier spp. (24).

b. Sierra Nevada in California--Prunus emarginata, Arctostaphylos nevadaensis (34).

c. Bitterroot Mountains in Idaho--Amelanchier spp., Prunus emarginata, Holodiscus discolor, Rosa spp., Symphoricarpos spp. (19), Xerophylum tenax, Vaccinium myrtillus (36).

d. Central Montana--Vaccinium scoparium, Cercocarpus ledifolius (36), Calamagrostis rubescens (39).

e. Southern Idaho, Utah, and Wyoming--Calamagrostis rubescens, Juniperus communis, Juniperus sibirica, Pachistima myrsinites.

f. Central Rocky Mountains in Colorado--Shepherdia canadensis, Vaccinium scoparium.

Closely uniform, mature stands of lodgepole pine do not favor the presence of vertebrate animals. When stands are opened up by fire or cutting, the usual faunal influx common to many forest types follows. Squirrels, chipmunks, mice, and birds destroy great numbers of lodgepole pine seeds, but their effect on inhibiting reproduction appears to be insignificant because of the frequent heavy cone crops and high germinative capacity of the seeds.

LIFE HISTORY

Most of the known facts about the life history of lodgepole pine were derived from observations and studies on the inland form and primarily from the Intermountain and Rocky Mountain regions. This form is not only the more widespread of the two, but is by far the more important commercially.

Little emphasis is placed upon the coastal form of lodgepole pine in present day forest management in the United States. The following statements, therefore, apply mainly to lodgepole pine in its range of greatest commercial importance in this country and in Canada; namely, northern Colorado, western and southern Wyoming, western and central Montana, northern Utah, southern Idaho, southern Oregon, western Alberta, and southern British Columbia.

SEEDING HABITS

Flowering and fruiting.--Little specific information is available regarding flowering of lodgepole pine in different parts of its range. Time of pollen shedding shows both annual and geographic variation. Suggested dates for collecting pollen for breeding work correspond closely with the dates when shedding begins (21). Three-year records at latitude 39° N., longitude 120° W. at 6,000 feet above sea level near Lake Tahoe, California, show the earliest collection date for pollen from the inland form to be June 5, the latest date July 8, and the mean date June 22. The mean collection date for pollen from the coastal form in a single year's observations at latitude 39° N., longitude 124° W. near Point Arena, California, was June 9.

Cones from the current year's crop (inland form) mature in August and September and in September and October (coastal form) (66). When they are fully ripe the scale tips are shiny and a light brown color; their inner portion is a bright purple brown (58). The cones are subcylindric-to-ovoid-shaped, small (3/4 to 2 inches long), and frequently have asymmetrical bases.

Most of the viable seed is borne on scales nearest the tip of the cone, except for the first few scales. The extreme basal scales and all undeveloped scales are generally barren. Usually the seeds are entirely in the upper half of the cone (5).

Fertile seeds of good quality are normally black or slightly grayish because of the presence of minute excreta of resin. A brown color denotes incomplete seed development and therefore low vitality. Hollow seeds invariably are almost white, or black with large white blotches. Fertility is not related to seed size (5).

During their development, conelets frequently tend toward one-sidedness. This results in a flattening or even a concavity of the undeveloped side. Failure of pollen to reach the surface of the conelet closely appressed to a stem or branch, and lack of sufficient light in this area for physiological functions to progress, have been given as possible explanations (5).

A recent study (14) shows that maximum cone asymmetry is associated with large angles of cone attachment to the branches and with high cone specific gravity. This is especially true of the asymmetrical cones from trees growing in the Rocky Mountains. Cones from trees in the Sierra Nevada, which have a low specific gravity and which are attached to the branches at approximately right angles, have maximum symmetry.

Seed production.--Cones bearing viable seed are produced at an extremely early age--in open-grown stands by trees from 5 to 10 years old; in more heavily stocked stands by trees from 15 to 20 years old. Seed from trees less than 10 years old have shown a germination percentage as high as seed from mature trees. Commercial cone-bearing ages are from 50 to 200 years (39).

Lodgepole pine is a prolific seed producer. Good crops occur at 1- to 3-year intervals with light crops intervening (5, 8, 40, 66).

The number of fully developed seeds per cone varies widely, from as few as 1 or 2 to as many as 50. In one study an average of 26 seeds per cone was determined on nine national forests in Colorado and Wyoming (39). Another study showed an average of 40 for large lots of cones (5). Unpublished results of several small tests in Idaho and Montana show averages between 20 and 25 seeds per cone.

Cone production per tree varies; consequently, the number of seeds per tree also varies. Averages of 50,000 and 21,000 seed per tree from old and new cones together were found on areas in Idaho and Colorado, respectively (13). Obviously seed yields per acre vary considerably and can be estimated only in a general way. For example, an annual yield of 320,000 seed per acre was estimated for an area in central Colorado and 73,000 per acre for an area in southern Wyoming for the 10-year period, 1912 to 1921 (5).

Geographic differences in the closed-cone habit of lodgepole pine have been recognized. In most coastal populations serotinous cones are uncommon. Notable exceptions occur on the Mendocino white plains in northern California (42) and sporadically in areas not in the immediate vicinity of the coastline, mainly in the low mountains of the northwestern corner of California and southwestern corner of Oregon (14).

Throughout much of the inland distribution cones are generally serotinous, but even here many exceptions are found. Whereas in the Rocky Mountain and Intermountain regions the closed-cone habit is widespread, in the Sierra Nevada cones open at maturity (22, 14). Trees in the Oregon Cascades, the eastern Siskiyou Mountains, and in southern and Baja California also reportedly have nonserotinous cones (14). Other areas where cones have been reported to be mainly nonserotinous are the Deschutes Basin in Oregon (67) and the Blue Mountains in northeastern Oregon (65).

In stands that have closed cones, individual trees may have both serotinous and nonserotinous cones, and a preponderance of either kind (16).

The closed-cone habit has considerable silvicultural significance. Where serotinous cones are abundant, as in the Rocky Mountain region, a large quantity of sound seed is available for release following fire or cutting. One study showed the maintenance of an amount equal to about three times the average current crop in closed persistent cones (5). Germinative potential declines slowly and much of this seed remains viable for a long time. Viable seeds have been extracted from serotinous cones 75 to 80 years old (41), and a few seeds were germinated from 150-year-old cones imbedded in wood (44).

Closed cones of lodgepole pine in slash. These cones are the principal source of seed for a new stand following cutting operations.

The basic reasons for "serotiny" in lodgepole pine, its exact geographic distribution, and the degree of its occurrence within a stand must be dealt with area by area. The presence of serotinous cones cannot be taken for granted.[6/]

Although certain vertebrate animals, insects, birds, and subfreezing weather may exact a toll on the cone crop each year, these agencies have a negligible silvicultural effect on cone crops.

Seed dissemination.--Lodgepole pine seeds are small (approximately 102,000 seeds per pound for the inland form and 135,000 per pound for the coastal form). In still air the seeds fall at an average rate of 2.7 feet per second. Their average weight is 0.0055 gram (55).

Seed from standing trees are disseminated throughout the year but not at a uniform rate. In Montana in a pure, even-aged, overmature stand in 3 out of 4 years, only 20 percent of the yearly crop disseminated was released during August and September. Sixty-two percent was shed during October to June of the following year, and 18 percent during June and July (9).[7/] In an uncut overmature stand over a 4-year period, sound seeds were released at the rate of 17,000 per acre per year. On the average in each year 80 percent of the seed came down prior to the following growing season.

6/ For more complete discussions of the closed cone habit of lodgepole pine, see Critchfield (14) pp. 60-61 and 66-67; Crossley (16); and Clements (13).

7/ In 2 years of record on the Pringle Falls Experimental Forest, Oregon, most of the seedfall occurred during September and October; only about 10 percent occurred between November 1 and June 1 of the following year. (Written communication from E. L. Mowat, Bend, Oregon, dated April 23, 1956.)

In the subalpine forest region of Alberta, Canada, during 3 years of study in a 60-year-old stand, maximum annual seedfall occurred over a 4- to 5-week period and climaxed the first week of October; however, small amounts were released continuously throughout the year (15).

Although wind is normally the principal agent in seed dissemination, it is not important in dispersal so far as management of the species is concerned (64). Seed dissemination by wind suitable for restocking open areas is seldom beyond 200 feet from the parent trees (9, 41).

The most important seed dissemination from a management standpoint occurs following logging operations. This dispersal comes from cones attached to the slash and from cones knocked from the slash and scattered over the forest floor. Maximum seed release from this source takes place after the first year of cone exposure to the natural elements (9); some further release occurs for as long as 6 or more years (61).

Fire is not a requisite for seed release from closed cones stored in the slash (6, 60). Usually the resin that seals the scales together melts at 113° F. (45° C.) (13). When this occurs the scales are free to flex and spread apart. This can occur under natural conditions without fire when enough heat reaches the cone surface through radiation, convection, or conduction (17). On the other hand, fire may hasten the opening of some cones that are not suitably positioned for the resin bond to be melted or softened by solar heat.

The relationships between cone opening, seed availability, and initial stand density suggest that the relative amounts of seed available for release may be controlled by careful disposal of slash with heavy machinery and fire used judiciously. Burning slash windrows, concentrations, and dozer piles that are one-twentieth acre or less in area and that occupy not more than 25 percent of the total area cut has little detrimental effect on regeneration (9).

VEGETATIVE REPRODUCTION

Lodgepole pine has been grafted successfully on mature ponderosa pine (46) and on Scotch pine (*Pinus sylvestris*) (30). It does not reproduce naturally by sprouting.

SEEDLING DEVELOPMENT

Establishment.--Lodgepole pine seed generally has persistent vitality and a high germinative capacity without pretreatment. Although stratification is not needed, it does hasten and improve germination (66).

The viability of seed in closed cones in the slash is affected by cone position. In one study (61) in 6-year-old slash, seed from cones above ground had about twice the germinative energy and germinative capacity of seed from cones on the ground.

Most viable seed germinate in the spring following dispersal, but a small amount may germinate a year later because of the occasional embryo dormancy exhibited by this species (66). Fluctuating temperatures between 47° and 78° F. favor germination (5). For subsequent growth and development, soils having a slightly acid reaction produce best.

Best germination occurs in full sunlight and on mineral soil or disturbed duff that is free of competing vegetation. For this reason a clear cutting system is most desirable for reproduction of this species. On many areas, however, lodgepole pine has become established in the shade of lightly cut or uncut stands. Such reproduction may persist for many years, but it is rather unusual among intolerant tree species.

Early growth.--Lodgepole pine seedlings are frail in appearance and root slowly (5). A taproot is formed. In one study (25) taproots were found not to persist beyond the juvenile years. However, more recently it has been shown that the taproot is maintained but may be bent, stunted, atrophied at its extremity, or obscured by other roots in the system (31). The lateral roots develop horizontally outward compared to those of ponderosa pine, which grow obliquely downward (25). Later, especially on deep soils, the laterals may develop deep sinkers, giving the root system a heart-shaped form (31). Light sandy soils that hold most of their moisture at considerable depth favor deep rooting. Furthermore, these light soils do not, after denudation, encourage a heavy growth of herbaceous vegetation (5).

Seedling establishment and early survival on south slopes benefit from partial shade, which retards losses of soil moisture and protects from heat due to prolonged, direct insolation.

Early growth rates are good but they vary with locality and site. On the Deerlodge National Forest, Montana, in typical fully stocked stands on slightly better-than-average site, 20-year-old dominant trees average 1.9 inches d.b.h. and 12 feet in height.

Lodgepole pine frequently regenerates too abundantly. Overstocking often results in growth stagnation at extremely early ages. A striking example of this was found on a burn in Montana where a single milacre quadrat was stocked at the rate of 765,000 10- to 11-year-old trees per acre (37). These trees ranged in height from 4 to 25 inches. Other studies on burns in Montana report plots having as many as 300,000 1-year-old seedlings per acre, and in 8-year-old stands up to 175,000 trees per acre, averaging about 2 feet high. In Colorado 10 small sample plots in a 22-year-old stand established after a fire showed an average of 44,000 trees per acre (39). The tendency of this species toward overstocking and stagnation is therefore probably the most extreme of any tree species on the North American continent.

Seasonal growth data on lodgepole pine are available from the east slope of the Rocky Mountains in Alberta and the Sierra Nevada in California only. In the subalpine forest of Alberta leader growth of saplings for a 4-year period consistently started in early May and continued for 12 weeks. However, within each growing season the distribution of growth differed widely from year to year. Trends of weekly leader elongation were similar but rates differed according to aspect. Growth on a south aspect was consistently greater than on other aspects, and was directly related to corresponding mean weekly temperatures, except toward the end of the growing season (32).

Eight years of record from the west slope of the Sierra Nevada, at about 5,200 feet elevation, show that lodgepole pine begins height growth earlier than its common tree associates in this locality. For example, 88 percent of the seasonal height growth of lodgepole pine was completed before white fir started height growth. About 60 percent of the seasonal height growth of lodgepole pine was completed at the time of needle emergence from the fascicle sheath, and all of it was completed before needle growth ceased. Lodgepole pine also ceased height growth before any of its tree associates in this region (23).

SAPLING STAGE TO MATURITY

Growth and yield.--Lodgepole is one of the smaller pines and shows remarkable range in stand density and striking reactions to both density and environment (56, 62). For example, in the Rocky Mountains one study in 100-year-old stands of varying density showed a maximum yield of 20,000 board feet per acre with 800 trees; yield fell off rapidly to less than 1,500 board feet when the number of trees increased to 1,800 (41). Similar effects on the cubic-foot yield of the stands and upon the average height and diameter of the trees were shown. Stagnated stands 70 years old may have as many as 100,000 trees per acre, averaging only 4 feet in height and less than 1 inch in diameter at the ground.

On the average, yields of 12,000 to 15,000 board feet per acre are considered good in old-growth Rocky Mountain lodgepole pine. Yields of 20,000 to 25,000 board feet per acre are exceptional.

The stands that occur from Glacier National Park along the Continental Divide to south central Montana appear to differ from those in Colorado in several ways. Aside from differences in composition of the understory, the Montana trees are generally smaller. Yields per acre are also generally lower in Montana than in Colorado.

The low-elevation lodgepole that grows in northeastern Washington and adjacent areas in northern Idaho has a faster growth rate and dies earlier than the lodgepole pine at higher elevations in Montana. These stands generally start breaking up at 80 to 100 years.

Lodgepole pine does not prune well naturally. In open-grown stands branches are retained nearly to the ground. In dense stands the clearboled appearance of the trees is often misleading. Partial pruning of the bole for 10 to 25 percent of its length is common; however, pruning often does not progress to complete elimination of the basal portion of the branches.

Sizes attained vary according to locality. Within the main lodgepole pine region most trees at 140 years are 7 to 13 inches in diameter and 60 to 80 feet tall (41). In the Blue Mountains of Oregon at 100 years of age trees average 12 inches in diameter and 70 to 80 feet in height (28). At 100 years of age trees in the Sierra Nevada reach average diameters of 15 to 18 inches and average heights of 90 to 100 feet (28).

Trees of the coastal form vary greatly in size at given ages; mature trees from 6 to 20 inches in diameter and 20 to 40 feet tall occur. On a small plateau a few miles wide along the coastal plain of Mendocino County, California, an extreme condition is found where mature lodgepole pine is little more than a canelike dwarf 2 to 5 feet high (34). This dwarfed condition is associated with a highly acid hardpan soil.

The largest tree of this species on record is 19 feet in circumference at $4\frac{1}{2}$ feet above ground and is 106 feet tall (1). It is located outside of the main lodgepole pine region on the Sierra National Forest in California.

The oldest lodgepole pine stand on record was found on the Beaverhead National Forest in Montana (39). Its age in 1915 was 450 years. Individual trees as old as 600 years have been reported (14).

A 60-year-old stand of pure, even-aged lodgepole pine.

In fully stocked, pure, even-aged stands on medium sites in Montana (Deerlodge National Forest) average heights and diameters of the main stand 7 inches d.b.h. and larger are as follows:

Age (Years)	Height (Feet)	D.b.h. (Inches)
40	33	7.0
60	54	7.8
80	61	8.4
100	65	8.8
120	69	9.2
140	71	9.6
180	75	10.0

In stands of this kind the mean annual increment in cubic feet to a 2½-inch top culminates between 70 and 90 years, and in board feet, measured to a 6-inch top, at 130 years (40).

Since some localities have better average sites than those from which the above data were derived, rotation ages for fully stocked stands probably would be between 70 and 90 years for greatest cubic-foot return, and between 120 and 140 years for maximum large-size material. Such stands without thinning should yield 8,000 to 12,000 board feet per acre at rotation age.

The cubic-foot volume in fully stocked stands on some of the best sites in British Columbia (Site Index 80 at 80 years) for trees 6 inches and larger in diameter to a 3-inch top is as follows (11):

Age (Years)	Volume per acre (Cubic feet)
40	1,560
60	4,200
80	6,200
100	7,550
120	8,450
140	9,000

Climax position.--Ecologically lodgepole pine stands may be grouped into two categories: (1) subclimax stands and (2) seral stands.

1. Subclimax stands: In these stands lodgepole pine is being held indefinitely on the area by either natural factors other than climate or artificial factors.[8/] Stands of this kind exist in their present state because of isolation from effective seed supplies of species that have the natural

8/ In some places stands of this kind have occupied the site so long that they appear like climax plant communities. Where this occurs they may be true climax stands and probably will be managed as such by silviculturists.

potential for replacing them. This condition was initially brought about by fire. Both fire and present soil-water relationships play an important part in its maintenance. These virtually stable tree communities are usually pure lodgepole pine, but frequently minor amounts of other species are present.

2. Seral stands: In these stands lodgepole pine is only a temporary occupant of the site, as evidenced by one or more of the following conditions:

(a) appreciable amounts of advance reproduction of other species
(b) mixed composition of the overstory
(c) pure lodgepole pine of limited extent within stands of climax species or longer lived species such as western larch.

Seral lodgepole pine stands are never remote from the seed of species that can replace them.

Reaction to competition.--Lodgepole pine is a shade-intolerant species (3). It is more intolerant than any of its main associates except western larch, which is even more intolerant, and ponderosa pine, which is about as tolerant. However, despite its intolerance, which is most pronounced at early ages, lodgepole pine can maintain itself in extremely dense stands for as long as 80 to 100 years.

Lodgepole pine demands more moisture in the soil and air and a lower average temperature than Douglas-fir and ponderosa pine, but probably less moisture and a higher temperature than Engelmann spruce and alpine fir (58). Under exposed conditions lodgepole pine is at a disadvantage compared to ponderosa pine. It not only has a greater leaf area per unit of weight than ponderosa pine, but in windy atmosphere its water loss per unit of leaf area is four times greater (25).

Release.--Growth response to release by thinning is not certain and appears to be related to such factors as site, age, original stand density, and severity of thinning. Several stands have shown good response to heavy thinning at an early age (2, 39, 48, 52). Others have shown no release when thinned at ages as young as 14 years.[9] Evidence indicates that once stagnation has set in it may be difficult to overcome. Thinnings at an age as early as 7 years might need to be made if immediate release is expected (51).

At older ages, growth response to release is correlated strongly with crown size and vigor and the amount of release given (63).

9/ Written communication from D. I. Crossley, Alberta, Canada, dated September 24, 1956.

INJURIOUS AGENCIES

Insects.--The most serious insect enemy of lodgepole pine is the mountain pine beetle (Dendroctonus monticolae). This insect has caused extensive losses in both the United States and Canada. Occasional epidemics have virtually wiped out thousands of acres of this species. Trees from 4 inches in diameter up to the largest size have been attacked. During epidemics trees are attacked irrespective of their health or vigor. The beetles enter mainly along the bole from a few feet above ground up to the middle branches but may also attack the larger limbs and the entire main stem, excepting the extreme top (35). In seedling and sapling stands, such as those that have developed in block clear cuttings, this beetle should not cause much concern.

The lodgepole pine beetle (Dendroctonus murrayanae), a much less aggressive insect than the mountain pine beetle, attacks old or weakened trees at the base (35). Because it may develop in large numbers in freshly cut stumps, it may become troublesome in old growth along the edges of improvement cuttings or other types of partial cuttings.

In young stands the lodgepole terminal weevil (Pissodes terminalis) at times causes great damage by attacking the terminal shoot and causing distorted or forked trees (20, 35). It is particularly destructive in young open-grown stands in California.

The principal defoliating insects are the lodgepole needle miner (Recurvaria milleri), the lodgepole sawfly (Neodiprion burkei), and the spruce budworm (Choristoneura fumiferana).

Diseases.--Dwarfmistletoe (Arceuthobium americanum) is widespread throughout the lodgepole pine type and causes a large but as yet undetermined amount of growth loss (68). Reproduction that develops beneath infected overstory is most likely to become infected. Dwarfmistletoe appears to increase its vigor and "broom out" when partial cutting is practiced. Because of its prevalence in the lodgepole pine type, silvicultural management of the species must be positively geared to its control.

At least three stem rusts (Cronartium spp.) and several woodrotting fungi attack lodgepole pine. The rusts spread slowly and frequently cause misshapen boles. The wood fungi (Fomes pini and Polyporus schweinitzii and the root fungus (Armillaria mellea) are the most important decay organisms (10, 39, 50).

Fire.--Although serotinous cones can be opened by heat from fire and can withstand fire to some degree, they can also be consumed by fire. When this occurs the seeds necessary for regeneration are destroyed. Because of its relatively thin bark the tree itself is more susceptible to fire than Douglas-fir and any of the other pines with which it grows, but is less susceptible than Engelmann spruce and subalpine fir (39). Lodgepole pine trees killed by fire or insects may remain standing for 20 or more years. Standing dead trees decay slowly but often check so badly that merchantable lumber cannot be sawed from them (7).

A branch of lodgepole pine heavily infected with dwarfmistletoe.

Wind.--Because of its root habit lodgepole pine generally is considered susceptible to windfall, although, as with other species, its windfirmness varies with topography, soil conditions, and stand density. In many areas it is relatively windfirm, except where it develops shallow roots because of impermeable layers and excessively shallow, stony soils.

Animals.--Porcupines (*Erethizon epixanthum*) damage or completely girdle many trees. However, their destructiveness in relation to management of this species has not been determined.

Dwarfmistletoe brooms become abundant in infected stands which have been partially cut. The parasite eventually spreads to uninfected residual trees and its seeds shower down annually infecting young reproduction.

SPECIAL FEATURES

The volatile oil (turpentine) from the oleoresin of lodgepole pine consists largely of phellandrene, an unstable terpene having a boiling point higher than that of ordinary turpentine (54). This compound has been found in only one other species of pine--Coulter pine (*Pinus coulteri*) (45).

Lodgepole pine is a survivor from the Tertiary age in Yellowstone National Park. Knowlton (27, p. 667) found in Tertiary deposits in the park a fossil serotinous cone from a tree that he believed was the immediate ancestor of the lodgepole pine of today and later named *Pinus premurrayana*. Numerous other tree species that grew in the park during the Tertiary age have disappeared, mainly as a result of climatic change. The predominance of the lodgepole pine type over other contemporary forest types in this area attests its ability to withstand repeated fires.

RACES AND HYBRIDS

Evidence of climatic races of the inland form has been reported (66). Seed size varies in different parts of the range; the largest seeds are found to the south (Sierra Nevada). Seed planted in Finland from nine Canadian sources produced trees that varied in form, growth rate, and disease resistance. In Sweden, better trees were produced from seed from an Alberta, Canada provenance than from Colorado or Montana sources. After storage at low temperature, seed from warmer climates germinates more slowly than that from colder climates. Seed from higher elevations germinates better at low temperatures (66° F.) than seed from lower elevations. Correspondingly, seed from lower elevations germinates better at higher temperatures than high-elevation seed (26).

The most recent study of morphological and physiological variation in lodgepole pine (14) provides additional evidence of regional differentiation within the species. According to the author there are enough differences to justify separate taxonomic recognition to four groups of lodgepole pine. He designates these groups' subspecies, as follows:

Coastal group: *Pinus contorta* Douglas ex Loudon ssp. *contorta*
Mendocino white plains group: *Pinus contorta* ssp. *bolanderi* (Parl.) stat. nov.
Sierra Nevada group: *Pinus contorta* ssp. *murrayana* (Balf.) stat. nov.
Rocky Mountain group: *Pinus contorta* ssp. *latifolia* (Engelmann ex Watson) stat. nov.

Within some parts of the species distribution certain character gradients, or clines, are also expressed. Whether these gradients are environmental or whether they are genetically controlled has not been determined. Most of the morphological characters studied vary somewhat regularly with elevation but not with latitude. A summary of the main characters and their indicated variability is given in table 1.

Natural hybrids of lodgepole pine with jack pine (*Pinus banksiana*) are found in Alberta, Canada (47). Crosses between these two species can also be made by controlled pollination (53).

Table 1.--Variation in certain morphological characters for natural populations of lodgepole pine by geographic regions[1, 2]

Character	Coast regions		Inland regions	
	Coastal	Mendocino white plains	Sierra Nevada	Rocky Mountains
Cone specific gravity	Shows greatest regularity in variation pattern and clearest distinctions between geographic regions of any character. Sample mean range 0.50 to 0.79; tree mean range 0.43 to 0.89.			
	Intermediate 0.62 to 0.69	High 0.71 to 0.77	Low 0.50 to 0.67	High 0.64 to 0.79
Cone angle of attachment (mature cones)	Greatest variability in eastern parts of species range (Rocky Mountains), diminishing away from this zone. Sample mean range 81° to 139°; tree mean range 44° to 153°; individual cone range 30° to 170°.			
	Less variable; mostly reflexed	Less variable; mostly reflexed	Less variable; predominantly projecting or only slightly reflexed. Decreasing irregularly from north to south in Cascades and Sierra Nevada. Least variable in south Sierra Nevada (80° to 100°)	Variable; suberect, protruding or reflexed.
Cone symmetry	Variable throughout range. Maximum symmetry in Sierra Nevada. Maximum asymmetry associated with high specific gravity and large angles of attachment (reflexed cones)			
Leaf width	Mean width 1.5 to 1.6 mm. Range 1.0 to 2.5 mm. No absolute relationship with elevation for species in its entirety.			
	Uniformly near average 1.4 to 1.6 mm.	Uniformly narrow; about 1.3 mm.	Variable; elevational clines expressed. Sierra Nevada wider than Rocky Mountains at comparable elevations	
Leaf length	Sample mean range 3.1 to 7.1 cm.; tree mean range 2.4 to 8.9. Generally shorter with coastal sources than inland sources but much overlapping in size.			
Leaf resin canal frequency	Number ranges from 0 to 7; majority of leaves have 0, 1, or 2. Sample mean range 0 to 2.1; tree mean range 0 to 3.9.			
	Wide range; number increases from south to north. Includes extremes in number for entire species. None in Mendocino County, California	None. (Unique in the genus _Pinus_)	Wide range	Wide range
Stomatal subsidiary cells	Striking regional differences are exhibited in the shape of the flange (thickest portion of the subsidiary cell wall which controls the size of the outer opening of the epistomatal cavity), the shape of the epistomatal cavity, and the size of the outer aperture. The heritable nature of subsidiary cell shape is indicated by similar differences in plantation samples.			

1/ Based on Critchfield (14).

2/ Definition of geographical regions:

Coastal	Entire coastal distribution except Mendocino white plains
Mendocino white plains	Plateau area of highly acid hardpan soil along Mendocino County coast
Sierra Nevada	Sierra Nevada proper, Siskiyou Mountains, and Oregon Cascades
Rocky Mountain	Entire inland distribution except Sierra Nevada geographical region

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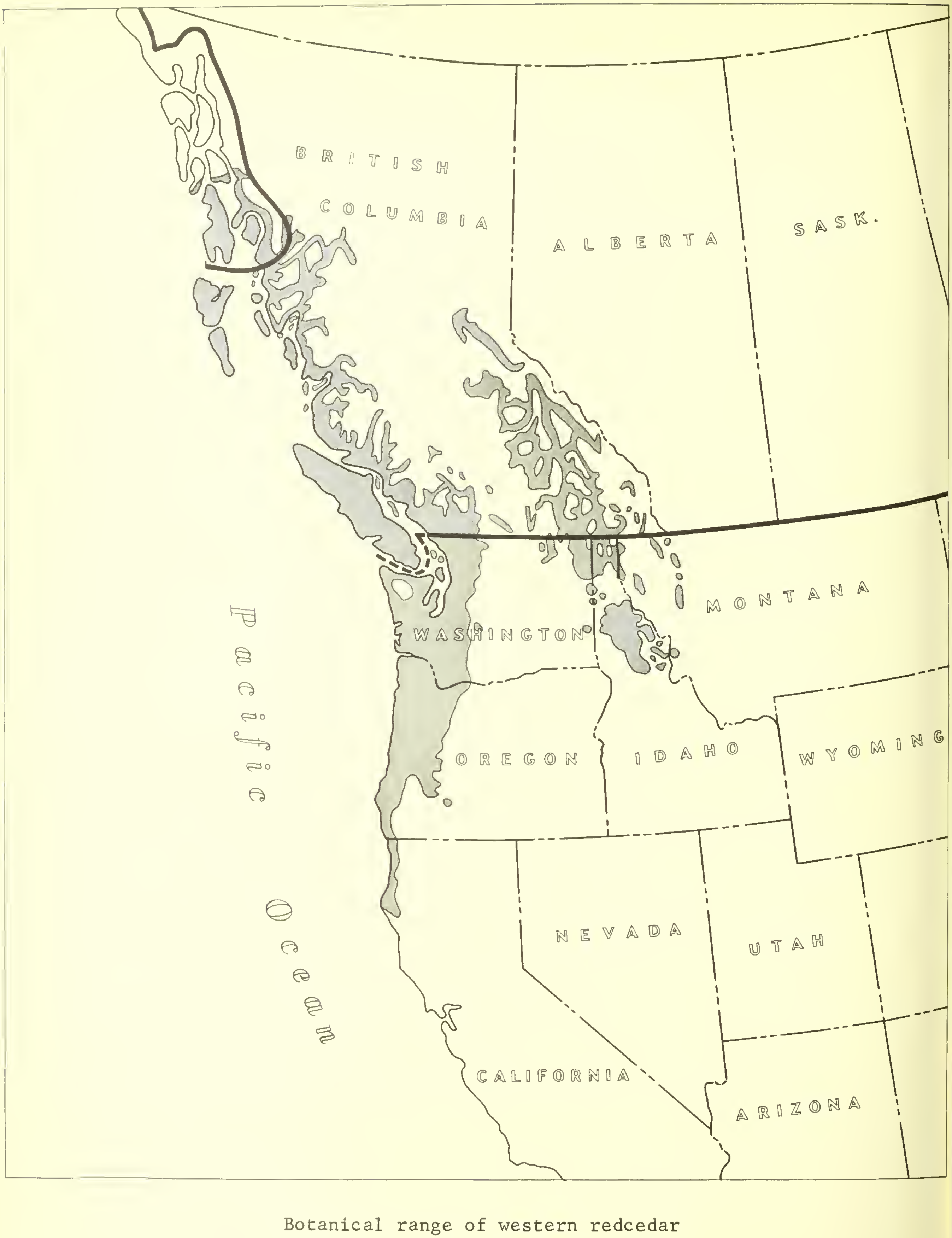
SILVICS of WESTERN REDCEDAR



Botanical range of western redcedar

Misc. Pub. No. 20 June 1959

SILVICS OF WESTERN REDCEDAR

By

Raymond J. Boyd, Jr.
Forester

INTERMOUNTAIN FOREST AND RANGE EXPERIMENT STATION
Forest Service
U. S. Department of Agriculture
Ogden, Utah
Reed W. Bailey, Director

FOREWORD

The SILVICS OF WESTERN REDCEDAR is the fifth publication in the series of seven silvics manuals being published by the Intermountain Forest and Range Experiment Station as part of a larger project sponsored by the U. S. Forest Service. Forest Service Experiment Stations over the Nation are issuing similar bulletins on many important North American tree species. Eventually, a single publication that will include the entire series will be issued by the U. S. Forest Service.

Information in this publication is based on selected references and unpublished data through 1957. The author will appreciate having any omissions of source material called to his attention.

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SILVICAL CHARACTERISTICS OF WESTERN REDCEDAR

By

Raymond J. Boyd, Jr.[1]

Western redcedar (Thuja plicata) is one of the most important commercial species in the Pacific Northwest, Alaska, and British Columbia. Local common names include giant arborvitae, canoe cedar, shinglewood, Pacific redcedar, giant cedar, arborvitae, and cedar (24).[2]

Western redcedar occurs from the coastal regions of southern Alaska (with northern limit at Sumner Strait (2)) south through the coastal ranges of British Columbia, through western Washington and Oregon to Mendocino County, California. In British Columbia it extends east to the western slope of the Continental Divide at latitude 54° 30' N. (11) and thence south into the Selkirk, Bitterroot, and Salmon River Mountains of Idaho. Its easternmost limit is the western slope of the Rocky Mountains in northern Montana. In Oregon western redcedar is found on both sides of the Cascade Range. On the west side it occurs as far south as Crater Lake, while on the eastern slopes its southern extent is limited to the vicinity of Mount Hood (34). It is rather uncommon in California and is confined to the ocean side of the coast ranges within the fog belt. Western redcedar has developed best in the fog belt of British Columbia and Washington (28). Throughout its range it occupies the humid transition and Canadian zones (1).

The commercial range of western redcedar in the United States is divided essentially into two regions (22); namely, the Inland Empire or northern Rocky Mountain region (western Montana, northern Idaho, and eastern Washington) and the West coast region (western Washington and northwestern Oregon).

1/ Forester, Intermountain Forest and Range Experiment Station, Forest Service, U. S. Department of Agriculture; stationed at research center, Spokane, Wash.

2/ Numbers in parentheses refer to Literature Cited, page 11.

HABITAT CONDITIONS

CLIMATIC

Throughout its range, western redcedar is confined almost entirely to regions having abundant precipitation and atmospheric humidity (34, 35). In the Puget Sound area it thrives under optimum growing conditions of abundant rainfall with cool summers and mild winters; here is its most favorable growing condition, and here it reaches maximum size. Average annual rainfall within the range of western redcedar varies from 30 to 60 inches at elevations up to 1,000 feet, and upwards to 100 inches at higher altitudes. Three-fourths of the precipitation falls during the wet season (November to April). In the Puget Sound area summer rains are infrequent. Within the fog belt, which extends about 30 miles inland from the coast, precipitation varies from 60 to 130 inches and includes fairly frequent summer rains. The mean annual temperature varies from 46° F. in the north to 52° F. in the south. The long growing season commences in April in the Puget Sound area and continues until September. Little of the precipitation falls as snow in the coastal and Sound areas, but at higher elevations a considerable part of the total precipitation is snow.[3/]

In the Inland Empire, where the western redcedar range generally coincides with that of western white pine, mean annual precipitation varies from 28 to 50 inches, depending on elevation and latitude. Average annual precipitation is about 28 inches in the northern portion and 32 to 49 inches in the middle and southern portions (15). The frost-free period, important for seedling establishment and cone development, ranges from 60 to 160 days in the Inland Empire (15). Growth of established trees is largely independent of the frost-free season, however.

The growing season is roughly the 4-month period from May through August, or about 120 days. The beginning of spring growth is probably limited by temperature, and growth ceases when soil moisture is depleted in August or early September. In the Puget Sound area the growing season continues from April through September.[4/] Length of the growing season varies so much with latitude and altitude that it is not easily defined.

The climate is characterized by a short summer season having scanty precipitation, rather low humidities, and a high percentage of clear days. Winters are long, snowfall is heavy and temperatures are fairly low. Precipitation in the Inland Empire is classified as the sub-Pacific type--distinguished from the Pacific type by the fact that in this sub-Pacific type only a small proportion of the total falls in winter, whereas a large proportion occurs in spring and fall (21). Thirty-five percent of the total precipitation in the

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3/ Personal communication from N. P. Worthington, Pacific Northwest Forest and Range Experiment Station.

4/ Ibid.

Inland Empire falls as snow; 50 percent is divided equally between spring and fall; 7½ percent falls in June, and the remainder is divided equally between July and August. Average annual temperatures range from 42° F. in the central part of the region to 50° F. at its southern border (15).

EDAPHIC

Little is known about the optimum soil texture classes and types, for western redcedar. It grows on a wide variety of soils from deep rich loams to shallow gravelly sands. More important than depth, texture, or fertility is the amount of available soil moisture (12, 22). Occasionally redcedar grows on moderately dry and warm sites, but its growth is poor (35). Both good soils and abundant moisture are necessary for best development. Larsen (23) found that cedar requires soil conditions in which moisture does not fall below 12 percent in August.

Daubenmire (5) has studied some of the soil characteristics of widely scattered stands in northern Idaho representing the three associations in which cedar is climax. In these stands the pH in the first 5 decimeters of mineral soil varied from about 5.1 to 7.1. Most of the soils studied could be characterized as slightly to moderately acid. Spruce-fir associations located at higher elevations have more acid soils, and the lower elevation associations have less acid soils, but none are strongly basic. Soils under individual cedar trees exhibit higher pH than soils under hemlock trees in the same stand. This condition is associated with a high calcium content of cedar foliage (6, 36). Moisture equivalents in these same soils varied from 11 to 82 percent and thus represented a very wide range of soil texture and structure (5).

PHYSIOGRAPHIC

Because it grows best in moist soils, western redcedar is generally found on stream bottoms, moist flats, terraces, and gentle lower slopes and in moist gulches and ravines (26, 34, 35). The environment of a north aspect is generally more suitable than the more severe southerly aspect.

Throughout its north-south range on the Pacific coast it occurs down to sea level. In Alaska it is confined to the islands and to the western side of the coastal ranges to an elevation of about 3,000 feet. In coastal British Columbia it grows on the islands and extends up the coast range to an elevation of 2,400 feet. In the Olympic Mountain coast ranges and west slopes of the Cascades in Washington it rarely exceeds an elevation of 4,000 feet. In Oregon it extends generally to 5,000 feet but in one location to 7,000 feet (34). On the east slope of the Washington Cascades and in the northern Rocky Mountain region of northeastern Washington, northern Idaho, and Montana, it is found between 2,000 and 7,000 feet (35). The upper limit in the British Columbia Selkirk range is 4,500 feet (11). Within the United States its growth is not commercially important above the 3,000-foot elevation in the coastal region or above 5,000 feet in the Inland Empire (34, 35).

BIOTIC

Western redcedar is a component of the following forest cover types described by the Society of American Foresters (33): western redcedar, western redcedar--western hemlock, western hemlock, western white pine, Douglas-fir--western hemlock, Pacific Douglas-fir, Sitka spruce, Sitka spruce--western hemlock, Pacific silver fir--hemlock, Port Orford cedar--Douglas-fir, redwood, larch--Douglas-fir, and Engelmann spruce--subalpine fir. The first three of these types make up the greater part of the climax forests of the Pacific Northwest and the humid interior region. For the most part, the extensive western white pine and Douglas-fir types are subclimax to these three climax types. The remainder of the types are largely climax in which cedar associates with the climax species in various proportions (5, 33).

A more definitive classification of vegetation on an ecological basis in the northern Rocky Mountain area has been made by Daubenmire (5). Western redcedar occurs in three of his habitat types, namely, the Thuja-Tsuga/Pachistima, the Thuja-Tsuga/Oplopanax, and the Thuja/Pachistima associations.

Western redcedar seldom occurs in pure stands and then only over small areas. Its numerous associates vary from area to area. In Oregon, western Washington, and northward along the Pacific Coast, western hemlock (*Tsuga heterophylla*), Sitka spruce (*Picea sitchensis*), grand fir (*Abies grandis*), Douglas-fir (*Pseudotsuga menziesii*), Port Orford cedar (*Chamaecyparis lawsoniana*), and Pacific silver fir (*Abies amabilis*) are common associates. In California it grows in mixture with redwood (*Sequoia sempervirens*) and western hemlock. Bigleaf maple (*Acer macrophyllum*), red alder (*Alnus rubra*), and northern black cottonwood (*Populus trichocarpa* var. *hastata*) are common companions of cedar on very wet or swampy areas in the coastal region. In the upper Cascade Mountains it grows with Pacific silver fir, Alaska cedar (*Chamaecyparis nootkatensis*), mountain hemlock (*Tsuga mertensiana*), western white pine (*Pinus monticola*), and noble fir (*Abies procera*) (22). In the northern Rocky Mountains, western white pine, western larch (*Larix occidentalis*), lodgepole pine (*Pinus contorta*), grand fir, Engelmann spruce (*Picea engelmanni*), subalpine fir (*Abies lasiocarpa*), western hemlock, and northern black cottonwood are commonly associated with cedar (15). Its Alaskan associates are western hemlock and Sitka spruce (37).

Dense stands of western redcedar and its associates commonly exclude nearly all subordinate vegetation, but when stands are at all open the forest floor abounds in a wide variety of mosses, ferns, herbs, and shrubs (5). In the northern Rocky Mountains the most common shrubby associates listed by Daubenmire (5) are: *Acer glabrum* var. *douglasii*, *Amelanchier alnifolia*, *Arctostaphylos uva-ursi*, *Ceanothus velutinus*, *Lonicera utahensis*, *Menziesia ferruginea*, *Oplopanax horridus*, *Pachistima myrsinites*, *Physocarpus malvacens*, *Ribes lacustre*, *R. viscosissimum*, *Rosa gymnocarpa*, *R. spaldingi*, *Rubus pedatus*, *Salix barclayi*, *S. bebbiana*, *S. scouleriana*, *S. sitchensis*, *Sorbus scopulina*, *Spiraea betulifolia*, *Symphoricarpos albus laevigatus*, *Vaccinium membranaceum*.

Most of these species occur both in the coastal redcedar forests and in the Rocky Mountain forests. In addition, the following species are plentiful in the coastal forests: Acer circinatum, Mahonia nervosa, Cornus nuttallii, C. pubescens, C. stolonifera, Corylus californica, Gaultheria shallon, Holodiscus discolor, Osmaronia cerasiformis, Malus fusca, Sambucus callicarpa, and a number of species of Betula, Ribes, Rubus, Salix, and Vaccinium not found in the Inland Empire (19).

LIFE HISTORY

SEEDING HABITS

Flowering and Fruiting.--Little has been reported about the phenology of western redcedar. On the warmer sites, flowering probably commences as early as mid-April (4). At higher elevations flowering may be delayed until late May or early June. In most areas the cones mature by late August, and seedfall starts in late August or early September. In the Inland Empire, Haig (15) reports that seedfall is rather light in September, heaviest in October, and that from 34 to 40 percent of the seedfall occurs after November 1. Some seedfall continues throughout the winter in most areas. Olson (27) has reported cedar bearing seed at the age of 16 years on the 1910 burn in northern Idaho.

Seed Production.--Western redcedar is a prodigious seed producer, ranking second only to western hemlock among the associated species (15). Average annual seed crops from 100,000 to 1,000,000 seed per acre in stands with as much as 25 percent cedar have been reported for British Columbia (30). In the same area seed crops as great as 57,000,000 seed per acre within a stand of 67 percent cedar have been reported. In the Inland Empire, Haig has reported average annual seed crops over a 7-year period of 111,000 seed per acre on cutover areas. A 14-year record of cone crops in the Inland Empire shows the average interval between good cone crops for western redcedar to be 2.8 years. During an 8-year period in which detailed records were kept, western redcedar produced good crops 4 years, fair crops 3 years, and a poor crop only 1 year (15). In studies of seed production in British Columbia, Garman (10) reports a seed yield of 1,500,000 per acre from a fair crop on four bearing trees per acre.

Seed Dissemination.--Seed is disseminated by wind, but its relatively small wing surface causes its rate of fall to be faster than that of any of its associates (32). Consequently cedar seed makes the shortest flight and is not dispersed as well as the seed of its associates. In seed release experiments in the coastal forests, Isaac (17) found that western redcedar seed was not dispersed more than 400 feet from its source when released at 150 feet elevation.

VEGETATIVE REPRODUCTION

Cedar can be propagated vegetatively (39), and natural regeneration by this means appears to be common in some areas (30). In old growth stands on good sites in British Columbia most of the advanced reproduction may be vegetative. Adventitious roots may develop on low hanging limbs, from the trunks of fallen trees that remain alive, or by living branches that fall on a wet soil surface. Growth of such reproduction is very slow. Vegetative propagation has not been reported to be common in stands within the United States.

SEEDLING DEVELOPMENT

Establishment.--The seed of western redcedar is less liable to rodent depredations than that of its larger seeded associates. Direct seeding experiments in the Inland Empire (31) and in the coastal forests (18) have shown that the small seeds of western redcedar need no protection from rodents for successful establishment of a stand. This is probably true of naturally cast seed as well.

Depending on weather conditions, seeds germinate in the fall or early in the following spring (15, 22). In the coastal areas, fall germination and seedling establishment are common (22, 34). Spring germination is more common in the Rocky Mountains (15). Adequate moisture in the seedbed assures successful germination on any natural surface (22, 26).

Compared to other species in the western white pine type, cedar has the highest greenhouse germination percentage (cedar 73 percent, hemlock 65 percent, western white pine 44 percent, and grand fir 12 percent) (15). In greenhouse germination tests where a favorable degree of moisture was maintained, Fisher (8) found no differences in germination between ash, duff, mineral soil, and rotten wood surfaces. Under natural conditions, germination is much more favorable on burned and unburned mineral surfaces than upon duff. Rapid drying of the duff and the small size of cedar seeds probably account for the poor germination on this medium (15).

Although seed production of western redcedar is prodigious, rodent depredations of the seeds minor, and germination percentage excellent under most conditions, still a very small proportion of the seeds develops into established seedlings. Reports of first-year seedling mortality vary from 44 percent in a seed-tree cutting (15) to 97 percent under a dense cedar overwood (40). In the same seed-tree cutting, the 6-year mortality was 74 percent.

It is believed that biotic agents (principally fungi) cause the greatest early mortality. Activities of these various agents are extremely variable. Haig (15) reports early first season losses of as much as 47 percent from fungi, birds, and insects. The biotic agents of mortality are active only during the early part of the growing season. After seedlings start to harden, these agents of mortality give way to the physical agents of insolation and drought. In full sunlight few of the relatively succulent cedar seedlings can survive the scorching temperatures at the soil surface, and those which do soon die in a futile race to reach the receding soil moisture. Seedlings survive best under partial shade where there is sufficient sunlight and warmth for vigorous top and root growth. In full shade the seedlings make very poor top and root growth and soon die of drought because the necessary soil moisture is out of reach of the poorly developed root system. Only western hemlock has poorer seedling root penetration than cedar among the associated species in the northern Rockies (15).

Other factors being equal, seedling survival for the first 5 years is usually best on natural mineral soil, intermediate on duff, and poorest on rotten wood. Soil moisture again is the key to good early survival (15).

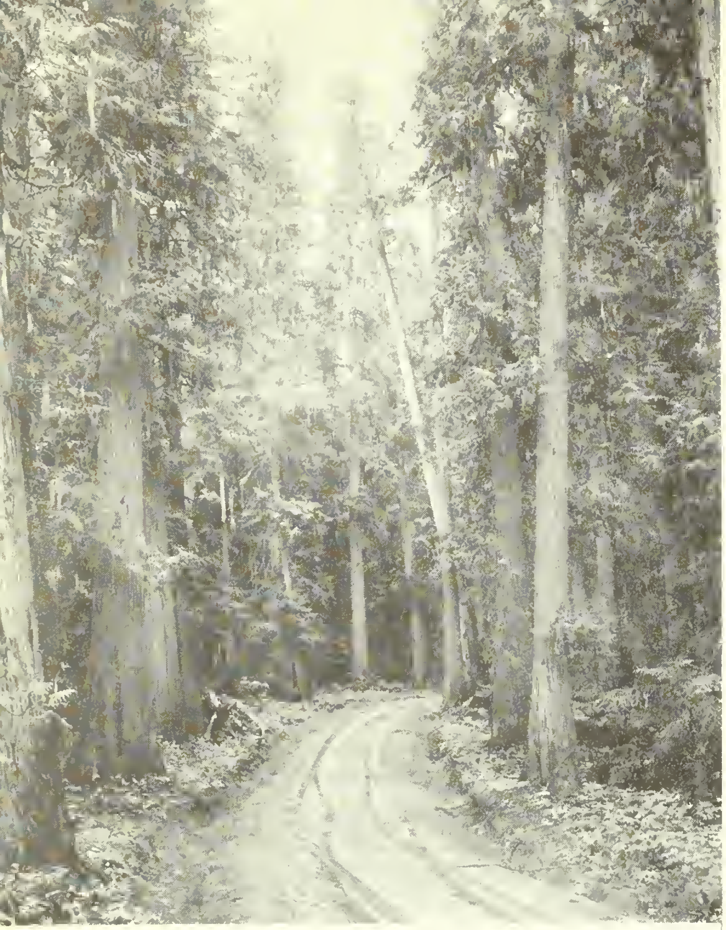
Another cause of mortality that may be important on cutover areas is smothering by the fallen leaves of deciduous shrubs. This is a primary cause of low survival on areas seeded directly to western redcedar (31).

SAPLING STAGE TO MATURITY

Growth and Yield.--Compared to most of its associates, western redcedar is a slow growing species. In the Puget Sound region under optimum conditions its average annual diameter growth is only 0.25 inch and its average annual height growth is only 1.58 feet during its first 50 years. By comparison, Douglas-fir adds 0.31 inch to its diameter and 2.04 feet to its height annually. Western hemlock is intermediate in its growth rates (22).

In young thrifty stands in the Puget Sound area, periodic annual diameter growth varies from a peak of 0.34 inch in the third decade to 0.20 inch in the seventh decade. Height growth was maximum at 2.3 feet annually in the second decade and declined to 0.61 foot in the seventh decade. At 80 years, the average diameter was 19 inches, height 101 feet, and volume 57 cubic feet, or 298 board feet per tree. Periodic annual volume growth had increased from 4.9 board feet per tree during the fifth decade to 6.4 feet per tree in the seventh (22).

In a typical mature stand that had grown under partial suppression, diameter growth was nearly uniform (varying from 0.12 to 0.18 inch per year) for nearly 200 years. Height growth was most rapid before the 30th year but was also steadily sustained for 200 years ranging from 1.0 to 0.53 foot per year. The average diameter at 80 years was 9.35 inches and the average height 63.3 feet. Volumes at 80 years were 11.5 cubic feet and 55 board feet per tree. Periodic annual board-foot growth per tree was 1.8. At 200 years the average diameter was 29.3 inches, height 131.1 feet, volumes 152 cubic and 850 board feet per tree. Annual growth was 11.0 board feet per tree (22).



An overmature western redcedar stand, Kaniksu National Forest, Idaho.

Thus, although suppressed stands of cedar do not grow nearly as rapidly as vigorous, free-growing stands, their growth is quite uniform and well sustained for at least two centuries. Generally, maximum diameter and height growth occur during the first 30 years; by that time other species have gained the lead and hold cedar in an intermediate position for many years (22).

Growth rate, sizes attained, and yield vary greatly from the best development attained in the Pacific region to the small-sized trees produced in the Rocky Mountain region. Under the most favorable growing conditions in the Puget Sound area cedar reaches enormous size: heights in excess of 200 feet, and diameters up to 16 feet (38). In the northern Rockies the larger trees are 175 feet high and 8 feet in diameter (26).

Since western redcedar usually grows in mixture with other species, separate yield tables are not available. Estimated yields in some of the best northern Idaho stands are from 25,000 to 30,000 board feet per acre. Pure stands of limited extent may yield from 60,000 to 70,000 board feet per acre (26). Stands in the western white pine type that contain cedar and hemlock generally have smaller yields than do stands in which these species are not abundant (14).

Cedar is classed as a very tolerant tree and, in fact, it germinates, grows, and even reaches maturity in the shade. Its growth is retarded in proportion to the density of the shade, however; and when competition is removed, cedar responds well to the increase in growing space. Apparently in some localities it does not fill all of the requirements of a tolerant species, however. Recent reports from British Columbia (30) describe mature commercial stands that have a notable absence of the younger diameter classes of cedar associated with abundant regeneration of western hemlock and white fir. Only in open-grown, noncommercial stands of the "cedar scrub" was there a distribution of diameter classes typical of tolerant species. This lack of advanced reproduction under heavy shade is attributed to germination failures or seedling mortality rather than to the lack of ability of the species to survive under competition. Similar conditions have been reported in southeastern Alaska, where germination appears to be adequate but seedlings fail to survive (13).

INJURIOUS AGENCIES

Fire.--Redcedar has few important natural enemies other than fire. Its thin, fibrous bark and shallow roots make it an easy victim of fire (22, 26). In old stands fire burns out the hollow boles and leaves the tree little support. Reproduction is easily destroyed by surface fires. Studies in the coastal forests have shown that cedar is more severely damaged by surface fires than any of its associates. However, cedar grows chiefly on moist sites and is therefore less subject to fire damage than some associates. In Inland Empire stands, its relative fire resistance is rated as low-medium; Engelmann spruce, western hemlock, and alpine fir are more susceptible and in that order. The hot fires common in this region generally erase all evidence of differences in fire resistance between species except that western larch and Douglas-fir seem to have somewhat better survival than others (9).

Wind.--On the drier sites where good root anchorage is established, cedar withstands destructive winds quite well. On very wet soils, the shallow root system and poor anchorage make it more subject to windthrow (22). Tentative ratings of the windfirmness of Inland Empire species by Marshall (25) place redcedar fourth, exceeded by western larch, ponderosa pine, and Douglas-fir.

Snow.--Since much of the range of western redcedar lies within the area of heavy snowfall, some snow damage occurs. No data have been published on the importance of snow-caused mortality and damage in cedar. Snow is the outstanding cause of mortality in dense, immature stands of the western white pine type where cedar is an important component (15). However, cedar with its drooping conical crown may shed snow more readily and be less liable to direct snow damage than its associates.

Insects.--Cedar has few insect enemies and suffers little from insect damage (22). The western cedar borer (*Trachykele blondeli*) mines into the sapwood and heartwood of living, dying, and dead cedar. A round-headed borer, the amethyst cedar borer (*Samanotus amethystinus*), occasionally kills healthy trees, but usually limits its attacks to injured or dying trees.

Its range is limited to the coastal cedar forests. The western cedar bark beetle (Phloeosinus punctatus), a widespread species, attacks trunks and larger limbs and has been known to kill trees. Other less destructive insects that may occasionally cause noticeable damage are the hemlock looper (Lambdina fiscellaria lugubrosa), various cedar twig and leaf miners of the genera Gnathotrichus and Trypodendron, and various bark beetles of the genus Phloeosinus (20).

Diseases.--Cedar is not plagued by fungi to the extent that its associates are, but losses can strongly influence management. Buckland's studies (3) in British Columbia have shown that decay in stands 50 to 450 years old does not exceed growth increment but that decay in younger stands was more important than previous reports had indicated. He lists the following species of fungi, in order of decreasing importance, for the coastal areas: Poria asiatica, P. albipellucida, Fomes pini, Merulius sp., and P. subacida. In the interior, where losses from decay and incidence of infection are appreciably higher, species are as follows: Poria asiatica, P. weirii, Fomes pini, Polyporous balsameus, Merulius sp., and Poria subacida. Other extensive but less important fungi attacking the heartwood of living trees are Fomes annosus, F. nigrolimitatus, F. pinicola, Armillaria mellea, Omphalia campanella, Polyporus schweinitzii, and Coniophora arebella. Throughout the range of cedar the yellow ring rot caused by Poria weirii is probably the most serious (16). Cedar needle spot (Keithia thujina) sometimes reaches epidemic proportions in attacking seedlings and young trees. It often attacks older trees but such attacks are not as serious as those on younger trees. As much as 97 percent of western redcedar reproduction has been reported killed in its first season by this disease. It is apparently favored by high humidity and may be fostered by late spring snow cover (16, 29, 40).

Winter damage to young cedar trees can reach serious proportions. Particularly heavy damage to cedar has been reported when severe cold waves followed mild autumn weather (7).

Of greater silvical importance than the diseases and insect enemies of western redcedar itself are the enemies of its associates. Most of its arboreal companions are much more prone to insect and pathological attacks than is cedar--a factor that tends to hasten the succession of cedar to climax position.

RACES AND HYBRIDS

Tests of western redcedar from several sources in the United States and Canada have demonstrated wide variations in frost hardiness, indicative of definite racial variation in the species. Trees grown from inland seed sources were hardier than those from coastal areas (39).

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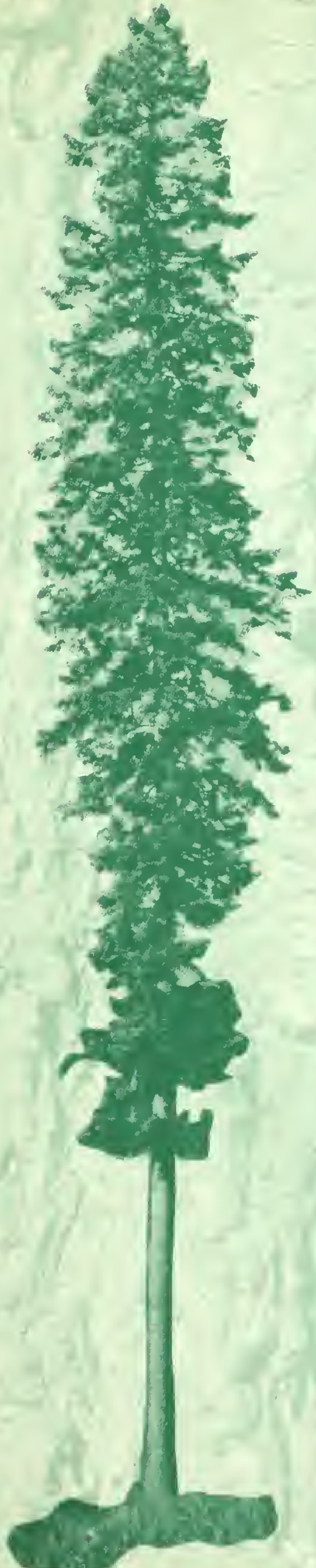
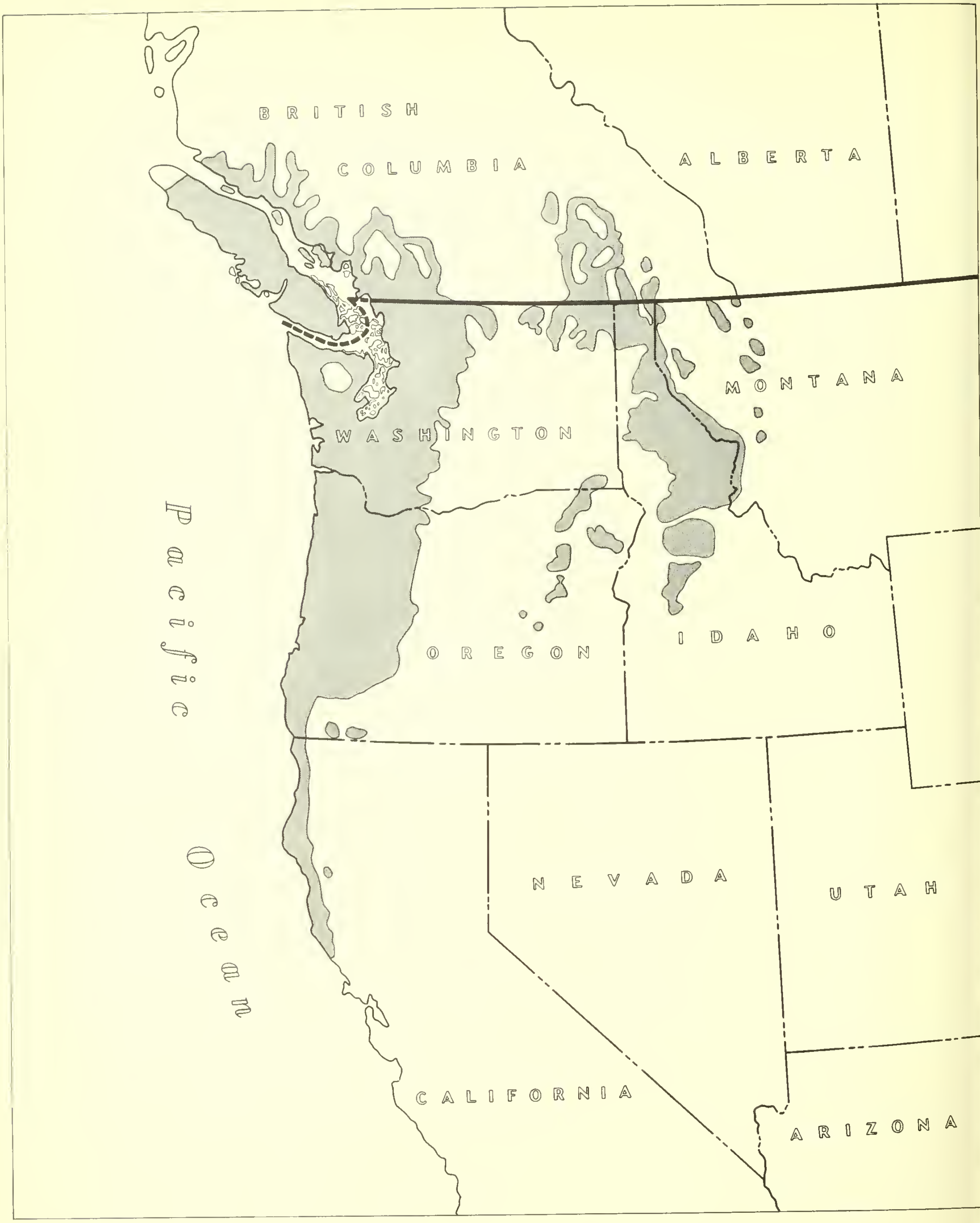


SILVICS of GRAND FIR



Botanical range of grand fir.

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SILVICS OF GRAND FIR

By

Marvin W. Foiles
Forester

INTERMOUNTAIN FOREST AND RANGE EXPERIMENT STATION
Forest Service
U. S. Department of Agriculture
Ogden, Utah
Reed W. Bailey, Director

FOREWORD

The SILVICS OF GRAND FIR is the sixth publication in the series of seven silvics manuals being published by the Intermountain Forest and Range Experiment Station as part of a larger project sponsored by the U. S. Forest Service. The other silvics manuals prepared by the Intermountain Station include ponderosa pine, lodgepole pine, western larch, western redcedar, and black cottonwood. Eventually a single publication on the silvics of many important North American tree species will be issued by the U. S. Forest Service.

Information in this publication is based on selected references and unpublished data through 1958. The author will appreciate having any omissions or apparent misinterpretations called to his attention.

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SILVICS OF GRAND FIR

By

Marvin W. Foiles[1]

Grand fir (Abies grandis) (11)[2] is one of the two balsam firs found in the northern Rocky Mountain region and one of seven in the Pacific Northwest. Except in the southern part of its range, where it is often confused with white fir (Abies concolor), it is distinguished from other firs in its range by its needles, which are distinctly two-ranked. Grand fir differs anatomically from white fir only by the absence of stomata from the upper surface of grand fir leaves and the presence of stomata on the upper surface of white fir leaves (9). Other common names include balsam fir, lowland fir, lowland white fir, silver fir, yellow fir, and white fir (lumber).

Grand fir grows in the stream bottoms, valleys, and mountain slopes of northwestern United States and southern British Columbia. Its wide geographical distribution is from 51° to 39° N. latitude and from 125° to 114° W. longitude (13). In the Pacific Coast region it grows in southern British Columbia mainly on the lee side of Vancouver Island and the adjacent mainland (15), in rain-protected areas in western Washington and Oregon, and in northwestern California as far south as Sonoma County. The range in the continental interior extends from the Okanagan and Kootenay Lakes in southern British Columbia south through eastern Washington, northern Idaho, western Montana west of the Continental Divide, and northeastern Oregon (18). The best commercial stands of grand fir are in the Nezperce and Clearwater regions of northern Idaho.

HABITAT CONDITIONS

CLIMATIC

Grand fir occurs on a wide variety of sites. Average annual precipitation in its territory ranges from 20 to more than 100 inches in western Washington and Vancouver Island, where grand fir grows on the rain-protected sites and avoids the extreme rainfall belt on the west side of the Coast Range and the Cascades (13, 15). Annual precipitation in the Blue Mountains of eastern Oregon averages 14 to 40 inches (17). In northern Idaho, where the best commercial stands of grand fir are found, average annual precipitation is 20 to 50 inches (4). Most of this precipitation comes during the winter. Generally 15 to 25 percent of the annual precipitation falls during the growing season. On Vancouver Island, where average annual precipitation

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1/ Forester, Intermountain Forest and Range Expt. Station, Forest Service, U. S. Department of Agriculture, at research center, Boise, Idaho.

2/ Numbers in parentheses refer to Literature Cited, page 11.

ranges from 27 to 111 inches, summer precipitation throughout most of the range of grand fir is comparatively low; only 2 to 5 inches fall during June, July, and August (15). Average annual snowfall ranges from a few inches on the coast to more than 500 inches in the mountains (4, 13). McMinn (12) reported that in the Abies grandis/Pachistima association of northern Idaho summer soil drought rarely occurred.

Average annual temperatures range from 42° to 50° F.; the average growing season temperature is 57° to 66° F. The frostless season varies, ranging from about 60 to 225 days, and is very irregular from year to year. Frosts may occur in any month in the interior habitat. The average growing season varies from the fairly brief 100 to 140 days in northern Idaho to 185 days on the Olympic Peninsula in western Washington (4, 13).

EDAPHIC

Grand fir grows on soils derived from a variety of parent materials. It seems to grow equally well on soils derived from sandstone, lava-weathered rock, or granite and gneiss. In the Pacific Coast region and in the Willamette Valley of Oregon it occurs most abundantly on deep, rich alluvial soils along streams and valley bottoms and on moist soils provided with seepage (13, 15). In the inland regions it also grows best on the rich mineral soils of the valley bottoms; but it also grows well on shallow, exposed soils of mountain ridges and on pure pumice soils in central and eastern Oregon. Grand fir was rated a near failure in one planting test on heavy clay-loam soils of the western Olympic Peninsula (21).

PHYSIOGRAPHIC

Grand fir grows on Vancouver Island and the adjacent mainland of British Columbia at elevations between sea level and 1,000 feet (15). In the southern interior of British Columbia it occurs only in the moist valleys of such rivers as the Kootenay, Columbia, and Okanagan and their tributaries. In western Washington and Oregon, as in British Columbia, grand fir is predominantly a lowland species. Its sites in western Washington are valleys and stream bottoms having high ground water level (13). Elevations of these sites are usually between 600 and 1,000 feet. At elevations above 1,500 feet grand fir is replaced by Pacific silver fir (Abies amabilis). Grand fir occurs in western Oregon in the lowlands of all the river regions and in the lower west Cascades to an elevation of 3,000 feet (13). In northern California it occurs in the redwood region from near sea level to about 1,000 feet and in the mountains to about 5,000 feet (18).

On the coast and in Canada grand fir is restricted to the stream bottoms and lowlands; but in the interior regions in the United States where grand fir occurs, it grows up to the tops of mountain ridges (13). Consequently, elevations of grand fir sites are higher in the interior than on the coast. In the eastern Cascades of Washington, 3,000 to 4,000 feet constitutes the upper altitude limit while in the eastern Cascades of Oregon grand fir grows at 5,000 feet. In the Inland Empire, including the Blue Mountains of Oregon, it is found as high as 6,000 feet and as low as 1,500 feet, but it is usually found between 2,000 and 5,000 feet. In the Nezperce region of central Idaho, where grand fir reaches its maximum stand density, it grows well at altitudes of 4,000 to 5,000 feet (13). Some writers believe that the altitudinal limits of its range are set by a combination of air temperature and precipitation (10).

BIOTIC

Grand fir reaches its largest individual tree size in western Washington, Vancouver Island, and the redwood region of California. The maximum proportion of the stand structure, however, is reached in northern Idaho. The only extensive pure stands of grand fir are in the Clearwater and Nezperce regions of Idaho, where it often forms the dominant and climax stand. It forms part of the following habitat types in the Inland Empire as defined by Daubenmire (1): grand fir, western redcedar--western hemlock, western redcedar, and Engelmann spruce--subalpine fir. These associations cover the approximate range of the commercial western white pine type and extend beyond white pine to the south, east, and west in the Nezperce region of Idaho and the Blue Mountains of Oregon.

According to the Society of American Foresters' Forest Cover Types, grand fir occurs in 15 cover types (16). It is a major component of the grand fir--larch--Douglas-fir, western white pine, interior Douglas-fir, western redcedar--western hemlock, and western redcedar types.

Grand fir sometimes occurs in pure stands but is much more common in mixed hardwood and coniferous forests. In the Rocky Mountains of Montana it is associated with Douglas-fir (*Pseudotsuga menziesii*), western larch (*Larix occidentalis*), lodgepole pine (*Pinus contorta*), and ponderosa pine (*Pinus ponderosa*) (5). Associates in the white pine region of the Inland Empire are western white pine (*Pinus monticola*), western larch, Douglas-fir, western hemlock (*Tsuga heterophylla*), western redcedar (*Thuja plicata*), lodgepole pine, Engelmann spruce (*Picea engelmannii*), subalpine fir (*Abies lasiocarpa*), and northern black cottonwood (*Populus trichocarpa*) (13).

On the Pacific Coast grand fir grows with Sitka spruce (*Picea sitchensis*) and Pacific silver fir in addition to western redcedar, western hemlock, and Douglas-fir. It is also associated with these coast hardwoods: bigleaf maple (*Acer macrophyllum*), Oregon ash (*Fraxinus latifolia*) red alder (*Alnus rubra*), and northern black cottonwood (*Populus trichocarpa*) (5). Sprague and Hansen (17) reported grand fir growing with Oregon white oak (*Quercus garryana*) in the Willamette Valley. Haddock[3/] reported that grand fir grows in association with sugar pine (*Pinus lambertiana*) and incense-cedar (*Libocedrus decurrens*) in parts of southwestern Oregon. In California, at the southern limits of the range, it is found with redwood (*Sequoia sempervirens*), and at higher elevations with Shasta red fir (*Abies magnifica* var. *shastensis*), white fir, noble fir (*A. procera*), subalpine fir, and western white pine (5).

3/ Personal communication from Dr. P. G. Haddock, University of British Columbia, Vancouver, Canada.

Daubenmire (1) lists the following shrubs commonly associated with the Abies grandis/Pachistima climax association in northern Idaho: myrtle pachistima (Pachistima myrsinites), Utah honeysuckle (Lonicera utahensis), big whortleberry (Vaccinium membranaceum), mallow ninebark (Physocarpus malvaceus), Saskatoon serviceberry (Amelanchier alnifolia), snowberry (Symphoricarpos a. laevigatus), birchleaf spiraea (Spiraea betulifolia), and several roses including baldhip rose (Rosa gymnocarpa), and Spalding rose (Rosa spaldingi).

LIFE HISTORY

SEEDING HABITS

Flowering and fruiting.--Flowers are unisexual, the two kinds being borne in small conelike clusters in the early spring on branchlets of the previous season's growth and in different parts of the same tree. Male cones are ovoid or cylindrical and hang singly from the lower side of the youngest twigs of the center to upper half of the crown; the female conelets are globose or ovoid to cylindrical and stand singly and erect on the uppermost part of the crown (18). The cones, mostly yellowish green and occasionally greenish purple, ripen in September of the same year (5, 19).

Extreme frosts may occasionally inhibit normal cone and seed development. Several species of insects feed on the buds, conelets, and seeds of grand fir, sometimes destroying 10 to 25 percent of the year's seed crop (8).

Seed production.--Seed production begins at about 20 years of age and production increases with age (19). Cone production increases with the diameter and vigor of the tree. Eight-year observations of permanent sample plots from 1927 through 1934 show that grand fir was the least abundant seed producer of the species associated with western white pine. Grand fir produced no good crops and only two fair crops while western white pine produced two good crops and three fair crops. During the same 8-year period, western hemlock produced five good crops and two fair crops (4). Other sources place the interval between good seed crops at 2 to 3 years (19).

A good cone crop for grand fir in the Inland Empire is considered to be one that produces more than 40 cones per tree. A fair crop produces 21 to 40 cones per tree. The number of grand fir seeds caught annually in seed traps on two sample plots averaged 17,000 seeds per acre on the Kaniksu National Forest and 23,500 per acre on the Coeur d'Alene National Forest. Eight-year observations of seed traps under a 300-year-old stand on the Priest River Experimental Forest yielded 12,800 grand fir seeds per acre annually (4). The yield of cleaned seed per pound ranges from 12,600 to 44,300 and averages 23,200 (19).

Greater production of grand fir seed is reported from Canada than from the Inland Empire (2). Garman (2) reported the seedfall of a fair cone crop in a season when 12 grand fir trees on one acre bore one good crop, two fair crops, one poor crop, and eight no crop. Gross seedfall from the four producing trees was about 300,000 seeds per acre, 27 percent of which were viable.

Unpublished records[4] of cone crops on immature trees in British Columbia showed that in the 27-year period 1930 through 1956 there were 9 crop-years, a crop-year being defined as a season in which at least 50 percent of the trees bore a class III crop or better. For the grand fir in this study, class III to class I crops ranged from an average minimum of 200 cones to an average for class I of about 700 cones.

Seed dissemination.--When the cones are ripe the scales fall away and release the large-winged seeds, leaving only the central spike (19). Seed is dispersed by the wind and rodents. Most of the seed is disseminated in the early fall, about 5 percent falling before September 1 and 80 percent falling before the end of October. Seed sufficient to produce adequate reproduction may be distributed up to 400 feet from the parent tree, but the average distance is about 150 to 200 feet. Seed in the duff remains viable through only one overwinter period (4).

VEGETATIVE REPRODUCTION

In nature grand fir reproduction is entirely from seed. There have been no reports of propagation by cuttings or grafting.

SEEDLING DEVELOPMENT

Germination and establishment.--Grand fir seed germinates in the spring following one overwinter period on the ground. In nature, germination is quite variable but is seldom greater than 50 percent because of embryo dormancy, injury to seed during dewinging, insect infestation, and the perishable nature of the seed. Seed is often so heavily infested with insects that an entire crop may be a failure (19).

Results of greenhouse germination tests of grand fir seed are highly variable. Results of three sandflat germination tests in the northern Rockies, averaged below, show that grand fir had the lowest germination percentage among major associates of the western white pine type (4).

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

4/ Personal communication from E. H. Garman, British Columbia Forest Service, Victoria, British Columbia, Canada.

The Woody-Plant Seed Manual (19) reports germination percentages from various sources ranging from 1 to 98 percent with an average of 28 percent; these percentages were based on 30 tests. The average rate of grand fir germination in those tests was about average for the true firs (19).

True firs	Germination percent
Grand	28
California red	25
Noble	24
Pacific silver	22
Subalpine	38
White	34

In the Inland Empire, germination begins in late April or early May on exposed sites and a month later on protected sites where snow lingers late. It is practically completed by July 1 on exposed sites and by August 15 on protected sites. Germination is best on mineral soil, but on seed-tree cuttings grand fir germinates nearly as well on duff as on any other surface (4).

Studies of seedling survival in the Inland Empire indicate that more than 30 percent of grand fir seedlings die in the first season, and an additional 10 percent die the second season. Losses drop off rapidly after the first 2 years, and seedlings 3 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, especially damping-off fungi. However, fungi-caused mortality is very irregular (4). Later in the season as the soil begins to dry, mortality is due principally to insolation and drought. Insolation is the most important physical agent of mortality on exposed sites. Surface-soil temperatures are less important under shade or on sheltered sites, and under dense shade or on north slopes do not cause death (4). Grand fir is relatively resistant to heat injury: it is equal to western white pine and Douglas-fir and more resistant than western larch, western hemlock, and western redcedar (4). Grand fir seedlings are relatively resistant to drought on areas exposed to full sun because the deep initial root penetration protects them from drying of the surface soil. On heavily shaded, cool areas, drought is the most important physical cause of seedling mortality because initial root penetration is slower and even shallow drying of the surface soil may cause drought mortality despite ample soil moisture at deeper levels (4).

Early growth.--Initial survival and growth of grand fir are favored by a moderate overwood shade (4, 15). Under full sun it is largely subordinate to faster growing intolerant species. Under partial overwood shade grand fir is aggressive enough to form a considerable part of the dominant reproduction stand. After 20 to 30 years it maintains its position and makes most rapid growth in the open (4).

A 90-year-old grand fir stand, Coeur d'Alene National Forest, Idaho

SAPLING STAGE TO MATURITY

Growth and yield.--On optimum sites on the coast of Washington, grand fir reaches heights of 140 to 200 feet with breast height diameters of 20 to 40 inches; occasionally it reaches 250 feet in height and 50 inches in diameter (13). The largest tree recorded on Vancouver Island was 61 inches d.b.h. and 240 feet in height at 280 years of age (15). It is believed that grand fir in the redwood forests of California reaches diameters and heights as great as or greater than those attained in the coast Douglas-fir region.[5] In its best commercial range in northern Idaho, grand fir normally grows to 115 to 150 feet in height with diameters of 25 to 40 inches. On the pumice soils of eastern Oregon it attains heights of 100 to 130 feet with diameters of 20 to 36 inches. On exposed subalpine ridges of the Inland Empire, heights of 50 to 70 feet and diameters of 12 to 14 inches are common (13).

5/ Personal communication from Russell K. LeBarron, Pacific Southwest Forest and Range Experiment Station.

The rapid early height growth nearly equals that of Douglas-fir on the Pacific Coast and western white pine in Idaho. It is believed that the most rapid early height growth is on Vancouver Island where Müller (13) reported growths of 31.5 to 35.5 inches per year. Terminal shoots more than 3 feet in length are fairly common in that region, and trees 140 feet tall at 50 years of age have been measured (15). In Idaho early height growths of 6 to 8 inches on average sites and 12 to 14 inches on optimum sites have been reported. In the dry pumice soils of eastern Oregon average juvenile height growth up to 5 inches per year has been reported. On these dry sites good height growth is delayed until the taproots reach groundwater. At some time in the third decade, height growth receives considerable impetus and annual height growths of 20 to 36 inches or more are common (13). A relatively deep taproot enables grand fir to survive and grow well on rather dry soils and exposed ridges. On the moist sites the taproot is largely replaced by more shallow lateral roots.

In the upper crown levels growth is nearly equal to the more intolerant western white pine and Douglas-fir with which it is commonly associated. As an understory tree it commonly outgrows the more tolerant western hemlock and western redcedar.

Grand fir seldom grows in pure stands; therefore estimates of yields have value only in relation to mixed stands. In the western white pine region of the Inland Empire grand fir rates second only to white pine as a high yielding species. Analysis of plots used in compiling normal yield tables for western white pine revealed that stands containing large numbers of white pine or grand fir yielded somewhat more than the average (3). On fair to good sites (site index 50 to 60 feet at 50 years) predicted yields of normal stands in the western white pine type range from 49,500 to 68,700 board feet at 120 years (3).

INJURIOUS AGENCIES

During the period of stand development from establishment to maturity several agencies influence stand growth and yield. Grand fir is rated medium in fire resistance among species of the western white pine type (4); it is less resistant than thick-barked western larch, ponderosa pine, and Douglas-fir but more resistant than subalpine fir, western hemlock, and Engelmann spruce. Fire resistance is influenced by habitat. For example, in moist creek bottoms grand fir succumbs rapidly to ground fires; but on dry hillsides it is more fire resistant largely because of its deeper root system, thicker bark, and more open stand conditions. The needles are quite resistant to cold during the severest part of winter. In one study Parker (14) found that grand fir leaves withstood temperatures of -55° C. without damage. Sudden extreme drops of temperature in the fall occasionally damage needles, but they are seldom fatal. However, frost cracks and lightning scars appear more frequently on grand fir than on its associates in the Inland Empire. The cracks cause little direct mortality but become avenues of infection by decay fungi (13).

Snow is an outstanding cause of mortality in dense immature stands in the Inland Empire. On sample plots snow accounted for 48 percent of the total grand fir mortality measured in basal area (4).

Grand fir is intermediate in resistance to windthrow. It is susceptible to decay fungi, and trees containing root rot or decay are especially susceptible to wind breakage and windthrow (4).

Grand fir is susceptible to heart rot at an early age. Fungi enter the tree through dead lower branches (6) and such injuries as frost cracks, lightning scars, fire scars (13), and logging scars. Indian paint fungus (Echinodontium tinctorium) is the most destructive attacking fungus. Armillaria mellea and Poria weirii are the two most important root rot fungi. Poria subacida and Fomes annosus also attack grand fir (6). Susceptibility to early decay is one of the most important factors in management of the species.

Numerous insects attack grand fir, but most of them are secondary and have only minor economic importance. The spruce budworm (Choristoneura fumiferana) and tussock moth (Hemerocampa pseudotsugata) have caused widespread defoliation and mortality. The western balsam bark beetle (Dryocoetes confusus) and the fir engraver (Scolytus ventralis) are the principal bark beetles attacking grand fir (7). The fir cone moth (Barbara colfaxiana var. siskiyouana), the fir seed maggot (Earomyia spp.) and several seed chalcids destroy large numbers of grand fir cones and seeds (8). The balsam woolly aphid (Chermes picea), often called "gout disease of fir," has destroyed grand fir in Oregon (7) and is believed to be a serious threat in Mount St. Helens region of Washington.[6/]

Reaction to competition.--Grand fir is rated as tolerant in all associations in which it occurs. In the Willamette Valley it is the eventual climax type following Douglas-fir and Oregon white oak (17). In the Inland Empire it is more tolerant than any of its associates except western redcedar and western hemlock. It is the climax type on many sites too dry for redcedar or hemlock (13). In coastal British Columbia grand fir is reported similar to Sitka spruce in tolerance; that is, slightly more tolerant than Douglas-fir. It is the least shade tolerant of the true firs in British Columbia, and is much less tolerant than western hemlock, western redcedar, or Pacific silver fir (15). Grand fir is a versatile species which, although quite tolerant, has a growth rate nearly equal to that of western white pine. It often forms part of both the overstory and the understory.

Grand fir responds well to release. It can survive for many years in rather dense shade although the crowns are short and growth is slow. However, it can build crown readily when released, partly because of epicormic branching that permits rapid use of available growing space. In one study Weir and Hubert (20) reported that 75-year-old released grand fir trees developed a distinct secondary crown of epicormic branches below the original crown. On many trees this secondary crown was as large as the original crown. Mature grand firs respond well to release if the crowns are vigorous.

6/ Personal communication from George R. Staebler, Puget Sound Research Center.

Stagnation does not occur normally. Grand fir makes good growth in rather dense stands and produces high yields.

SPECIAL FEATURES

Grand fir forms epicormic branches that usually form short fuzzy patches on the bark, but they may occasionally produce large branches following release.

RACIAL VARIATIONS

According to the Woody-Plant Seed Manual (19), five climatic races have been distinguished differing in color of needles, bark thickness, and properties of wood. Müller (13) describes five fairly distinct climatic form regions of grand fir occurrence; the differences are mainly physiological and ecological.

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by

HAROLD F. HAUPT

DIVISION OF WATERSHED MANAGEMENT RESEARCH

INTERMOUNTAIN FOREST & RANGE EXPERIMENT STATION
FOREST SERVICE
U. S. DEPARTMENT OF AGRICULTURE
OGDEN, UTAH
REED W. BAILEY, DIRECTOR

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Harold F. Haupt
Division of Watershed Management Research

INTERMOUNTAIN FOREST AND RANGE EXPERIMENT STATION
Forest Service
U.S. Department of Agriculture
Ogden, Utah
Reed W. Bailey, Director

A METHOD FOR CONTROLLING SEDIMENT FROM LOGGING ROADS

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INTRODUCTION

Controlling sediment from logging roads on cutover ponderosa pine lands of southwestern Idaho is an acute problem. Such roads usually exist under unfavorable hydrologic conditions; often they are subjected to severe summer storms and spring snowmelt runoff. Furthermore they usually are located on steep slopes where they cut into highly erosive soils derived from acid igneous parent materials (primarily granite). This publication describes a method of protecting intervening slopes, other downhill roads, and stream channels from the damaging effects of sediment that originates primarily from roads higher on the slope. The method was developed from an understanding of the processes involved in erosion from roads and how these processes operate after an area has been logged.

Road construction on steep topography creates instability in the disturbed soil on the slope. But in time a stable soil condition tends to become reestablished on the disturbed areas. During this stabilizing period damage may result; therefore, it is important to encourage and facilitate the stabilization process to attain its maximum development in the shortest possible time without damaging other watershed values.

Secondary logging roads in southwestern Idaho are normally retired from continuous use after logging operations are completed. They are "put-to-bed" with self-cleaning drainage structures and reseeded with a grass mixture. This practice allows road runoff to be channeled from the road surface through open cross drains or ditches, but diverted water flowing onto the loose and highly erodible fill embankment often cuts gullies that are a major sediment source. The higher the fill embankment, the greater the amount of sediment likely to be produced and moved further downslope. As the amount of water in the ditch channel increases, sediment movement likewise increases. Fine sediment particles admixed with heavier particles, are often deposited as streamers of mud over litter or grassed slopes (fig. 1).

Where litter is shallow or the grass cover on the slopes is sparse, energy of the overland flow may be sufficient to erode small gullies and thereby add fresh sediment to the initial flow (fig. 1). While the initial sediment flow is eroding more soil, it drops some of its load upon contact with such slope obstructions as grass, trees, fallen snags, brush clumps, and logging slash. Eventually this flow is dissipated on the protective strip or, if the protective strip is too narrow the flow is carried onto lower roads and

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1/ Forester, Intermountain Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture, stationed at Reno, Nevada.

Figure 1.--Sediment dislodgment from an abandoned logging road, Beaver Creek, Boise National Forest.

skidtrails or into a drainage bottom. An important factor that determines whether the protective strip is wide enough to dissipate the sediment load completely is the density of slope obstructions.

This phenomenon of sediment movement occurs at varying degrees of intensity every year on and below abandoned logging roads. It is more pronounced in years when, singly or in combination, unusual climatic and hydrologic events create severe runoff. Conditions conducive to severe erosion are likely to occur shortly after road abandonment and before new plant cover can provide control. Therefore, the treatment method must (a) contain the abnormally severe runoff and not just the year-to-year runoff, (b) contain this runoff if it should occur early in the life of a road while the embankment slope is raw and most vulnerable to erosion, and (c) rely primarily upon cross ditches rather than upon revegetation alone. The method described in this paper includes these features plus the advantage of being adaptable at the time of road layout; it thus insures a more successful and less costly job of post-logging treatment.

DEVELOPMENT OF THE CONTROL METHOD

Information about logging roads used in developing this control method was collected in 1956 from an experimental area on the Little Owl Creek tributary of the Boise River. This site was chosen because the roads had been subjected to unusually severe climatic conditions and runoff the year after they were "put-to-bed" with cross ditches. Because of these conditions, it was believed that the drainage diverted from the road had probably caused very nearly the maximum sediment movement; hence the objects of an exploratory study were to measure sediment movement below the roads and to determine the related controllable site characteristics.[2/]

2/ Haupt, H. F. 1959. Road and slope characteristics affecting sediment movement from logging roads. Jour. Forestry 57: 329-332.

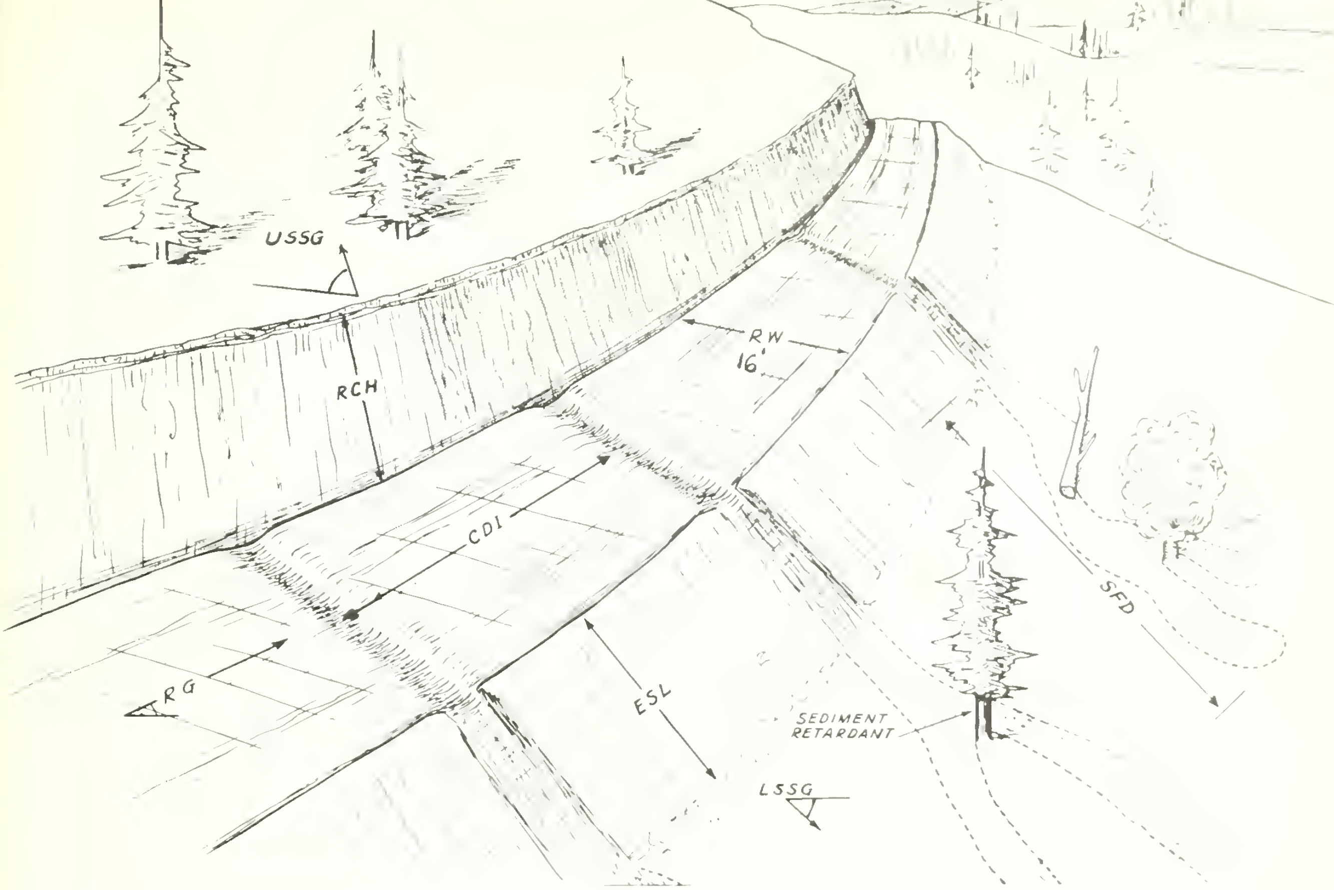

Figure 2.--Sediment flow distance and controllable road and slope characteristics.

Sfd - sediment flow distance

Rw - road width	Rg - road gradient
Cdi - cross ditch interval	Esl - embankment slope length (actual)
Rch - road cut height (vertical)	Lssg - lower side slope gradient

In selecting site characteristics likely to be related to sediment movement, certain physical characteristics of the soil were considered as probably being contributory. However, to expect the road locator to consider these when locating and treating a road was deemed impractical. Instead, road width, cross ditch interval, road cut height, road gradient, embankment slope length, slope obstruction index, and lower side slope gradient were selected because they are amenable to control or alteration by a road planner.

A multiple regression equation was developed relating sediment flow distance (Sfd) in feet to the four significant road and downslope characteristics: slope obstruction index (Soi), cross ditch interval squared $(Cdi)^2$, embankment slope length (Esl), and cross ditch interval times road gradient (Rg). Road width was sufficiently uniform to eliminate it as an important variable. All these characteristics except the slope obstruction index are shown in figure 2. The equation derived was:

$$Sfd=1.2871(Soi)+.0030(Cdi)^2+3.4918(Esl)$$
$$+.0468(Cdi \cdot Rg)-66.2395.$$

With proper substitution for the variables, this equation predetermines the distance or width of protective strip needed to dissipate sediment movement that may occur from a road to be built. Another way of using this equation is to have the estimated width of the protective strip (Sfd) given (as is possible after a road has been built), and then transpose the components of the equation so as to solve for any of the four variables. For example, to derive the slope obstruction index, let

$$Soi = \frac{Sfd - .0030(Cdi)^2 - 3.4918(Esl) - .0468(Cdi \cdot Rg) + 66.2395}{1.2871}.$$

Thus, the equation used in either of the above forms, establishes the basis for developing the proposed sediment control method.

Flexibility of the Equation Variables

This method of predicting necessary measures for road location and treatment provides considerable flexibility because two of the variables that affect sediment movement are readily subject to direct control. These are cross ditch interval and slope obstruction index; the latter is susceptible to change by the placement of logging slash. Road gradient can be regulated only at the time the road is located, and then only to a degree because of the need for maintaining grade to gain access into an area where logs will be decked. The fourth variable, embankment slope length, is almost entirely fixed by the gradient of side slope topography.

Cross ditch interval

Cross ditch spacings provided in the several sections of table 2 are 30, 50, 70, 90, 110, and 130 feet. The 30-foot spacing is considered the practical construction minimum when heavy tractor equipment of the D-8 type is to be used. The 130-foot spacing is the maximum considered permissible and is discussed later in this paper.

Slope obstruction index

Slope obstruction index can not be measured directly, as it was in the exploratory study.[3/] Slope obstruction index is calculated by dividing the measured sediment flow distance by the total number of slope obstructions, including a value for the dominant interspace ground cover. In the tables this calculation was modified because the measured Sfd, as such, is nonexistent initially. In its place was substituted the slope distance over which sediment may flow, or the width of the actual protective strip.

For practical application, the Soi of a slope approximately equals the average spacing (in feet) of major obstructions along the direction of slope. A large index value indicates that the slope obstructions are spaced far apart, as on the open south slope in figure 3A. Conversely, a small index value indicates that the slope retardants are spaced close together as on the

3/ Ibid.

A

Figure 3.--A, an open south-facing slope on Pikes Fork, Boise National Forest. B, a densely covered north-facing slope on Bannock Creek, Boise Basin Experimental Forest, Idaho.

B

densely covered north slope in figure 3B. The closer the obstructions are spaced the more effective they are in slowing the movement of sediment downslope.

On undisturbed side slopes, a natural Soi is commonly not more than 10 on north exposures, 20 on east exposures, 30 on west exposures, and 40 on south exposures. In the following tables, these values represent the "poorest slope obstruction index" found on the respective slope exposures. At the time of road location, the user needs only to identify the slope exposure where the road will be constructed.

When applying erosion control measures after a road has been abandoned, it may be desirable to reduce the Soi on the protective strip. The index is reduced by placing logging slash in the gaps between the natural retardants directly below the cross ditch (fig. 4). Detailed steps for evaluating natural retardants and for placing logging slash are discussed later.

Road gradient

In the several sections of table 2, road gradient is classified in four percentage groups: 1-3, 4-6, 7-9, and 10-12. The user is cautioned against extrapolating beyond 12 percent.

Embankment slope length

The Esl is generally related to the side slope gradient as follows:

Side slope gradient (percent)	20-28	29-37	38-46	47-55	56-64
Embankment slope length (feet)	3-5	6- 8	9-12	13-16	17-20

The user is cautioned against extrapolating beyond the 56-64 percent slope gradients and 17-20 foot Esl classes. In locating roads, the slope of the

Figure 4.--Logging debris effectively retards sediment flow below a haul road.

topography can be measured and the value used in place of embankment slope length, while the latter is used in the road treatment phase.[4/]

APPLICATION OF THE METHOD IN ROAD CONSTRUCTION AND TREATMENT TO PREVENT WATERSHED DAMAGE

Before this method can be adopted for preventing watershed damage, standards of sediment control must be defined. Here it is well to distinguish between a sediment control method and sediment control standards. The method is the means for achieving a goal; here it is a technique for achieving sound erosion control. It cannot establish control standards; these must be set by the forest manager. In actual use of this method, the author recommends what appear to be practical and economical standards for logging roads situated on the granitic soils of southwestern Idaho.

First, however, two assumptions must be made:

1. Logging roads located on these soils are not stable.

2. Some soil movement must be expected, and limited amounts must be tolerated under severe runoff conditions.

The two basic standards for erosion control based on these assumptions are:

1. A distance of 200 feet is established arbitrarily as the maximum distance sediment shall be allowed to move downslope even under a combination of such extreme conditions as: side slope gradient, 56-64 percent; slope obstruction index, 40; road gradient, 10-12 percent; and cross ditch interval, not greater than 130 feet.

2. Not more than one out of six sediment flows (under severe runoff conditions) shall be allowed to extend into a drainage course or onto a lower road.[5/] These two standards define how far and how much sediment movement is permissible below logging roads.

What is the best way to apply the sediment control method to achieve these standards?

First, the road locator must recognize that this method is a field working tool designed to aid him. It is not a substitute for experience and good judgment. Knowing that considerable expense in terms of man-hours and equipment is required to effect erosion control, he must attempt to avoid (a) locating roads along extremely steep slopes, (b) locating new roads close to other roads and drainage courses, (c) building steep gradient roads, (d) building roads wider than 16 feet, (e) crossing draws where side slopes are

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4/ For discussion of the mathematical relationship, refer to appendix I.

5/ The statistical reasoning behind the selection of "one-sixth" is explained in appendix II.

steep, (f) making road junctions where slopes are steep, and (g) locating roads on south slopes (poorer Soi) when other slopes (better Soi) can be used to a greater advantage. The road locator must realize that he can save some of the cost of erosion treatment by exercising good judgment when the road is laid out.

Next to a good job of locating and building roads, close spacing of cross ditches provides the most economical way of preventing movement of embankment material and downslope erosion. This method stresses maximum use of cross ditches. Where narrow protective strips below roads require ditches as close as 130 to 50 feet apart, knowledge of the exact slope obstruction index is not even required. As a safety measure, the Cdi is reduced to compensate for the poorest Soi that may prevail on a given exposure.

However, there is a minimum practical limit (about 30 feet) on the closeness at which ditches can be spaced. This close spacing is associated usually with very narrow protective strips and implies that the slope obstruction index must be considered and probably reduced.

In summary, the following approach is most desirable in applying the control method:

1. Locate roads in the most favorable place for leaving ample protective strips.

2. Use cross ditches liberally as the main deterrent to erosion.

3. Reduce the slope obstruction index only where maximum use of cross ditches alone will not provide satisfactory sediment control.

How to Apply the Control Method Before Road Construction

The main purpose in applying this method before road construction commences is to provide the locator a quick and accurate check against positioning too much of any road too close to a drainage course or lower road. When flagging rights-of-way, the locator should attempt to keep away from streams and other roads at least a minimum distance; this distance depending upon the maximum (or limiting) side slope gradient and road gradient to be encountered on a given slope exposure. To help the road locator, a field guide developed from the main prediction equation (table 1) gives the minimum slope distance to the center line[6/] of the proposed road.

To see how table 1 is used, assume the locator plans to flag a road on a slope having a generally western exposure. By moving from point A, the main access road, and proceeding to point B, the location where logs will be

6/ The distance to center line includes the estimated Sfd, the safety margin of 47 feet added algebraically to the equation components, and the "center line correction" or distance from the toe of the embankment to the center of road (Esl + 8 feet). The poorest slope obstruction spacing common to the exposure under consideration is used in the equation.

Table 1.--Minimum slope distance to center line of the proposed road

Road gradient	Side slope gradient (percent)									
	20-28	29-37	38-46	47-55	56-64	20-28	29-37	38-46	47-55	56-64
Percent	Minimum distance to center line (feet)									
	NORTH					EAST				
1-3	20	40	50	70	90	40	50	70	80	100
4-6	30	40	60	70	90	40	50	70	90	100
7-9	30	50	60	80	90	40	60	70	90	110
10-12	30	50	60	80	100	50	60	80	90	110
	WEST					SOUTH				
1-3	50	60	80	100	110	60	80	90	110	130
4-6	50	70	80	100	120	60	80	100	110	130
7-9	60	70	90	100	120	70	80	100	120	130
10-12	60	70	90	110	120	70	90	100	120	140

decked, he learns either from ground reconnaissance or maps and photos that the proposed road must generally parallel a perennial stream and cross several side draws. He observes that the road gradient will probably not exceed the 7-9 percent class in order to gain point B and also observes that the side slope gradient between points A and B will not exceed the 47-55 percent class. Substituting in table 1 gives a minimum distance to center line of 100 feet. The locator ignores the side draw crossings but attempts to keep the center line at least 100 feet from the perennial stream at any location between points A and B.

However, should the road locator deem it necessary to locate a section of the road less than the desired minimum distance to center line, it is implied that the maximum permissible cross ditch spacing along this critical stretch of road will be 30 feet and that the slope obstruction index will probably have to be reduced by slash. The locator does not record this information in his Erosion Control Action Plan at this time because he must make a final check prior to staking cross ditches.

How to Apply the Control Method After Road Abandonment

For treating roads after cessation of logging operations, the main prediction equation can be readily adapted by permitting the existing distance across the protective strip to equal sediment flow distance and solving for either cross ditch interval or slope obstruction index. The method also affords a way of intensifying the degree of treatment as the slope distance between road and channel decreases. The purpose of intensified treatment is to make doubly certain that the bulk of sediment from roads will not traverse even the very narrow protective strips. Five intensities of treatment are prescribed depending upon the width of protective strip.

Protective Strips Wider than 200 Feet

Adhering to the erosion control standards discussed previously, roads having protective strips below them wider than 200 feet should not have any two cross ditches spaced farther apart than 130 feet, regardless of side slope gradient, road gradient, or slope exposure (see number 1, paragraph 3, page 7). This does not imply that the erosion control specialist should arbitrarily space ditches 130 feet apart. Obviously, it will be prudent to space ditches closer where a side draw or skidtrail intersects a road or where a road uncovers a perennial seep, to mention only two typical extenuating situations.

Protective Strips Narrower than 200 Feet

Where protective strips below roads are narrower than 200 feet, the erosion control specialist must observe on-the-ground factors before selecting the maximum permissible cross ditch spacing. These factors include slope exposure, embankment slope length, and road gradient. An estimate of the actual width of protective strip should be made.

As an aid to the user, a second field guide was developed from the main prediction equation in the form of tables 2.1-2.7 inclusive. These tables show the maximum permitted cross ditch spacing commensurate with values of the other observed factors.[7/] To illustrate how table 2 is applied, assume that on and below a given stretch of road the following conditions exist: width of protective strip, 71-80 feet; slope exposure, west; embankment slope length, 9-12 feet; and road gradient, 4-6 percent. Refer to table 2.3 and read a maximum permitted ditch spacing of 50 feet, which means that along this stretch of road to be "put-to-bed", no two cross ditches should be staked farther apart than 50 feet. Again, it should be repeated that this maximum spacing requirement does not preclude the possibility of spacing ditches closer where special features of terrain and cover suggest such action.

Protective Strips Narrower than 120 Feet

Where a protective strip below a road is narrower than 120 feet, some combinations of factors, especially on the more erodible south exposures, give a permitted cross ditch spacing of 30 feet (see tables 2.1-2.4 inclusive). Consequently, the protective strips below these 30-foot cross ditches may require a decrease in the slope obstruction index.

7/ The proper cross ditch interval is solved for in the equation by substituting the width of existing protective strip for the Sfd (including the safety margin of 47 feet) and by using the poorest slope obstruction index that may prevail on a given slope exposure.

Table 2.1.--Maximum permissible cross ditch interval for roads having protective strips narrower than 200 feet

Slope exposure	Embankment slope length	Width of protective strip (feet)											
		0-10				11-20				21-30			
		Road gradient (percent)											
		1-3	4-6	7-9	10-12	1-3	4-6	7-9	10-12	1-3	4-6	7-9	10-12
	Feet												
		Maximum cross ditch interval (feet)											
	3-5					50	30	30	30	70	50	30	30
	6-8	All				30	30	30	30	50	30	30	30
North	9-12	30				30	30	30	30	30	30	30	30
	13-16					30	30	30	30	30	30	30	30
	17-20					30	30	30	30	30	30	30	30
	3-5									50	30	30	30
	6-8	All				All				30	30	30	30
East	9-12	30				30				30	30	30	30
	13-16									30	30	30	30
	17-20									30	30	30	30
	3-5												
	6-8	All				All				All			
West	9-12	30				30				30			
	13-16												
	17-20												
	3-5												
	6-8	All				All				All			
South	9-12	30				30				30			
	13-16												
	17-20												

Table 2.2.--Maximum permissible cross ditch interval for roads having protective strips narrower than 200 feet

Slope exposure	Embankment slope length	Width of protective strip (feet): 31-40				41-50				51-60			
		Road gradient (percent)											
		1-3	4-6	7-9	10-12	1-3	4-6	7-9	10-12	1-3	4-6	7-9	10-12
	Feet	Maximum cross ditch interval (feet)											
North	3-5	70	70	50	50	90	70	70	50	110	90	70	70
	6-8	70	50	30	30	70	70	50	30	90	70	70	50
	9-12	30	30	30	30	50	50	30	30	70	50	50	30
	13-16	30	30	30	30	30	30	30	30	50	30	30	30
	17-20	30	30	30	30	30	30	30	30	30	30	30	30
East	3-5	70	50	30	30	70	70	50	30	90	70	70	50
	6-8	30	30	30	30	50	50	30	30	70	50	50	30
	9-12	30	30	30	30	30	30	30	30	50	30	30	30
	13-16	30	30	30	30	30	30	30	30	30	30	30	30
	17-20	30	30	30	30	30	30	30	30	30	30	30	30
West	3-5					50	50	30	30	70	50	50	30
	6-8					30	30	30	30	50	30	30	30
	9-12	All				30	30	30	30	30	30	30	30
	13-16	30				30	30	30	30	30	30	30	30
	17-20					30	30	30	30	30	30	30	30
South	3-5									50	30	30	30
	6-8									30	30	30	30
	9-12	All				All				30	30	30	30
	13-16	30				30				30	30	30	30
	17-20									30	30	30	30

Table 2.3.--Maximum permissible cross ditch interval for roads having protective strips narrower than 200 feet

Slope exposure	Embankment slope length	Width of protective strip (feet): 61-70				71-80				81-90			
		Road gradient (percent)											
		1-3	4-6	7-9	10-12	1-3	4-6	7-9	10-12	1-3	4-6	7-9	10-12
	Feet	Maximum cross ditch interval (feet)											
North	3-5	130	110	90	70	130	110	90	70	130	130	110	90
	6-8	110	90	70	70	130	110	70	70	130	110	90	70
	9-12	90	70	50	50	110	90	70	50	110	90	70	70
	13-16	70	50	50	30	90	70	50	50	110	70	70	50
	17-20	50	30	30	30	70	50	30	30	70	70	50	50
East	3-5	110	90	70	70	130	110	70	70	130	110	90	70
	6-8	90	70	50	50	110	70	70	50	110	90	70	70
	9-12	70	50	50	30	90	70	50	50	110	70	70	50
	13-16	50	30	30	30	70	50	30	30	70	70	50	50
	17-20	30	30	30	30	50	30	30	30	70	50	30	30
West	3-5	90	70	50	50	110	70	70	50	110	90	70	70
	6-8	70	50	50	30	90	70	50	50	110	70	70	50
	9-12	50	30	30	30	70	50	30	30	70	70	50	50
	13-16	30	30	30	30	30	30	30	30	50	50	30	30
	17-20	30	30	30	30	30	30	30	30	30	30	30	30
South	3-5	70	50	50	30	90	70	50	50	110	70	70	50
	6-8	50	30	30	30	70	50	30	30	70	70	50	50
	9-12	30	30	30	30	30	30	30	30	50	50	30	30
	13-16	30	30	30	30	30	30	30	30	30	30	30	30
	17-20	30	30	30	30	30	30	30	30	30	30	30	30

Table 2.4.--Maximum permissible cross ditch interval for roads having protective strips narrower than 200 feet

Slope exposure	Embankment slope length	Width of protective strip (feet) 91-100				101-110				111-120			
		Road gradient (percent)											
		1-3	4-6	7-9	10-12	1-3	4-6	7-9	10-12	1-3	4-6	7-9	10-12
	Feet	Maximum cross ditch interval (feet)											
North	3-5	130	130	110	110	130	130	130	110	130	130	130	130
	6-8	130	130	110	90	130	130	110	90	130	130	130	110
	9-12	130	110	90	70	130	130	110	90	130	130	110	90
	13-16	110	90	70	70	130	110	90	70	130	110	110	70
	17-20	110	70	70	50	110	90	70	70	110	110	90	70
East	3-5	130	130	110	90	130	130	110	90	130	130	130	110
	6-8	130	110	90	70	130	130	110	90	130	130	110	90
	9-12	110	90	70	70	130	110	90	70	130	110	110	70
	13-16	90	70	70	50	110	90	70	70	130	110	90	70
	17-20	70	70	50	30	90	70	70	50	110	90	70	70
West	3-5	130	110	90	70	130	130	110	90	130	130	110	90
	6-8	110	90	70	70	130	110	90	70	130	110	90	70
	9-12	90	70	70	50	110	90	70	70	130	110	90	70
	13-16	70	50	50	30	90	70	50	50	110	90	70	50
	17-20	50	50	30	30	70	50	50	30	90	70	50	50
South	3-5	110	90	70	70	130	110	90	70	130	110	90	70
	6-8	90	70	70	50	110	90	70	70	130	110	70	70
	9-12	70	50	50	30	90	70	50	50	110	90	70	50
	13-16	50	30	30	30	70	50	50	30	90	70	50	50
	17-20	30	30	30	30	50	30	30	30	70	50	50	30

Table 2.5.--Maximum permissible cross ditch interval for roads having protective strips narrower than 200 feet

Slope exposure	Embankment slope length	Width of protective strip (feet) 121-130				131-140				141-150			
		Road gradient (percent)											
		1-3	4-6	7-9	10-12	1-3	4-6	7-9	10-12	1-3	4-6	7-9	10-12
	Feet	Maximum cross ditch interval (feet)											
North	3-5	130	130	130	130	130	130	130	130	130	130	130	130
	6-8	130	130	130	110	130	130	130	130	130	130	130	130
	9-12	130	130	130	110	130	130	130	110	130	130	130	130
	13-16	130	130	110	90	130	130	130	110	130	130	130	110
	17-20	130	110	90	70	130	130	110	90	130	130	110	110
East	3-5	130	130	130	110	130	130	130	130	130	130	130	130
	6-8	130	130	130	110	130	130	130	110	130	130	130	130
	9-12	130	130	110	90	130	130	130	110	130	130	130	110
	13-16	130	110	90	70	130	130	110	90	130	130	110	110
	17-20	130	110	70	70	130	110	90	70	130	130	110	90
West	3-5	130	130	130	110	130	130	130	110	130	130	130	130
	6-8	130	130	110	90	130	130	110	110	130	130	130	110
	9-12	130	110	90	70	130	130	110	90	130	130	110	110
	13-16	130	110	70	70	130	110	90	70	130	130	110	90
	17-20	110	70	70	50	110	90	70	70	130	110	90	70
South	3-5	130	130	110	90	130	130	110	110	130	130	130	110
	6-8	130	110	90	70	130	130	110	90	130	130	110	110
	9-12	130	110	70	70	130	110	90	70	130	130	110	90
	13-16	110	70	70	50	110	90	70	70	130	110	90	70
	17-20	90	70	50	50	110	70	70	50	110	90	70	70

Table 2.6.--Maximum permissible cross ditch interval for roads having protective strips narrower than 200 feet

Maximum cross ditch interval (feet), by width of protective strip (feet) and road gradient (percent)

Slope exposure	Embankment slope length (Feet)	151-160: 1-3	151-160: 4-6	151-160: 7-9	151-160: 10-12	161-170: 1-3	161-170: 4-6	161-170: 7-9	161-170: 10-12	171-180: 1-3	171-180: 4-6	171-180: 7-9	171-180: 10-12
North	3-5	130	130	130	130	All 130				All 130			
	6-8	130	130	130	130								
	9-12	130	130	130	130								
	13-16	130	130	130	130								
	17-20	130	130	130	110								
East	3-5	130	130	130	130	130	130	130	130	130	130	130	130
	6-8	130	130	130	130	130	130	130	130	130	130	130	130
	9-12	130	130	130	130	130	130	130	130	130	130	130	130
	13-16	130	130	130	110	130	130	130	110	130	130	130	130
	17-20	130	130	110	90	130	130	130	110	130	130	130	110
West	3-5	130	130	130	130	130	130	130	130	130	130	130	130
	6-8	130	130	130	130	130	130	130	130	130	130	130	130
	9-12	130	130	130	110	130	130	130	110	130	130	130	130
	13-16	130	130	110	90	130	130	130	110	130	130	130	110
	17-20	130	130	110	90	130	130	110	90	130	130	130	110
South	3-5	130	130	130	130	130	130	130	130	130	130	130	130
	6-8	130	130	130	110	130	130	130	110	130	130	130	130
	9-12	130	130	110	90	130	130	130	110	130	130	130	110
	13-16	130	110	110	90	130	130	110	90	130	130	130	110
	17-20	130	110	90	70	130	110	90	70	130	130	110	90

Table 2.7.--Maximum permissible cross ditch interval for roads having protective strips narrower than 200 feet

Slope exposure	Embankment slope length	Width of protective strip (feet) 181-190				191-200			
		Road gradient (percent) 1-3	4-6	7-9	10-12	1-3	4-6	7-9	10-12
	Feet	Maximum cross ditch interval (feet)							
North	3-5								
	6-8								
	9-12	All 130				All 130			
	13-16								
	17-20								
East	3-5								
	6-8								
	9-12	All 130				All 130			
	13-16								
	17-20								
West	3-5	130	130	130	130				
	6-8	130	130	130	130	All 130			
	9-12	130	130	130	130				
	13-16	130	130	130	130				
	17-20	130	130	130	110				
South	3-5	130	130	130	130	130	130	130	130
	6-8	130	130	130	130	130	130	130	130
	9-12	130	130	130	130	130	130	130	130
	13-16	130	130	130	110	130	130	130	130
	17-20	130	130	110	110	130	130	130	110

To facilitate this, a third field guide (table 3) was developed from the regression equation; it gives the minimum number of slope obstructions needed below each ditch. Factors such as road gradient, embankment slope length, and width of protective strip determine the minimum number of obstructions required.[8/] A slope obstruction can be any major retardant including the dominant interspace ground cover. Each slope obstruction in the following list, except one form of interspace ground cover, has a value of 1, although four kinds of obstructions must exceed a minimum size before rating a value.

Major retardant		Value
standing tree	(3" diam.)	1
down snag	(3" diam. x 6')	1
fallen limb	(3" diam. x 6')	1
logging slash	(3" diam. x 6')	1
rock outcrop		1
tree stump		1
brush clump, usually higher than 2 feet		1
hummock		1
major depression in ground surface		1
Interspace ground cover		
grass or grasslike plants		1
brush stems, scattered and usually not more than 2 feet tall		2

As an example of how table 3 is used, assume that on and below a road requiring ditch spacing of 30 feet, the following conditions exist: width of protective strip, 51-60 feet; embankment slope length, 13-16 feet; road gradient, 4-6 percent; and actual number of slope obstructions, 4 (3 major retardants and 1 for grass cover). Table 3 shows that under this set of conditions the minimum number of 5 slope obstructions is needed. Because 4 obstructions are already present, only one needs to be added (fig. 5). On the other hand, if the actual number of slope obstructions equals or exceeds the computed minimum number, no additional treatment is needed below the cross ditch.

Protective Strips Narrower than 60 Feet

Wherever the protective strip below a road is narrower than 60 feet, some combinations of factors, especially on south exposures, require additional treatment measures such as "contiguous obstructions." Fortunately, such combinations of factors can be held to a minimum if the road locator uses <u>table 1 judiciously at the time of road layout</u>. Nevertheless, there are

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8/ This number is derived by solving for Soi. Let the width of protective strip equal the Sfd (includes the safety margin of 47 feet), and then divide the calculated Soi into the width of strip to obtain number of needed obstructions.

Table 3.--Minimum number of slope obstructions needed below cross ditches spaced 30 feet apart

Road gradient	Embankment slope length	Width of protective strip (feet)											
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-110	111-120
Percent	Feet	Number of slope obstructions											
1-3	3-5	2	2	2	2	2							
	6-8		8	3	2	2	2						
	9-12			13	6	3	3	3	2				
	13-16	Contiguous			18	9	4	4	3	3			
	17-20	obstructions 1/				23	19	5	4	3	3		
4-6	3-5	3	2	2	2	2	2						
	6-8		8	5	3	2	2	2					
	9-12	Contiguous		13	7	4	3	3	2				
	13-16	obstructions				23	5	4	3	3	3		
	17-20						28	7	4	4	3	3	
7-9	3-5	5	3	2	2	2	2						
	6-8			9	3	3	2	2	2				
	9-12				18	5	3	3	3	3			
	13-16	Contiguous				23	10	5	3	3	3		
	17-20	obstructions					28	13	5	4	4	3	
10-12	3-5		8	2	2	2	2	2					
	6-8			13	4	3	3	2	2				
	9-12				18	8	4	3	3	3	3		
	13-16	Contiguous				23	11	5	4	3	3	3	
	17-20	obstructions						22	6	5	4	3	3

1/ Obstructions placed close together perpendicular to the direction of slope with only enough space between to prevent the formation of a "corduroy" effect.

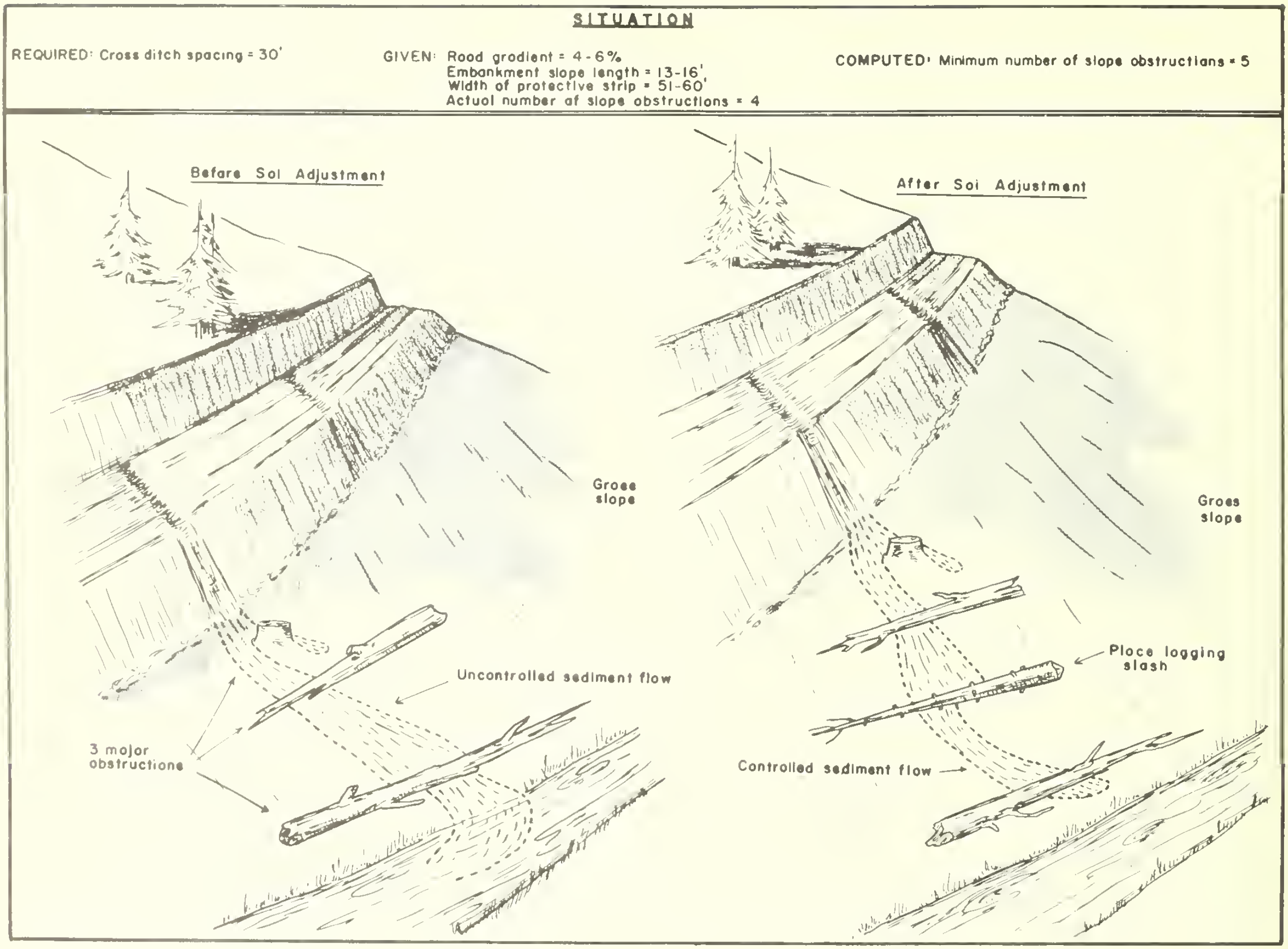

Figure 5.--How slope obstruction spacing is reduced by placement of logging debris.

places at stream crossings, at road junctions, or on switchback turns, where protective strips are very narrow, and therefore require additional treatment to handle the potential sediment movement likely to emanate from the road embankment. For instance, the treatment termed "contiguous obstructions" (table 3) calls for the placing of obstructions less than 1 foot apart across the direction of slope below the cross ditch. In using this treatment, care should be taken to prevent building a "corduroy path" for sediment to flow over, but instead to leave a space or crevice between obstructions in which the sediment may lodge.

Protective Strips Approaching Zero Width

Where protective strips approach zero width at the intersection of a road and side draw or stream channel, effective sediment control may be gained by bulldozing a wide "dip" in the road. This will remove much of the road fill material from the direct path of ephemeral or perennial streamflow.

APPENDIX I

Determining embankment slope length

Because embankment slope length cannot be measured when a road is laid out, two additional estimating equations were derived from field data collected in the original study.[9/] In the first regression equation, embankment slope length was designated the dependent variable and was related to several road and slope characteristics thought to be important in the basic design of a road. These included road width, road cut height, upper side slope gradient, and lower side slope gradient (fig. 1); they were tested singly and in various combinations. Of the characteristics tested, the product of road cut height (Rch) and lower side slope gradient (Lssg) was the single variable found to be statistically significant. By computing a regression coefficient for this variable, a prediction equation was derived in which

$$Esl=0.7637+0.0455(Rch \cdot Lssg)$$

with a standard error of estimate of 4.6 feet and 90 percent of the variation accounted for by the interaction of the two characteristics. Road cut height cannot be measured directly until after a road is constructed.

Accordingly, a second equation was developed in which road cut height was related to the slope characteristics, upper side slope gradient (Ussg) and lower side slope gradient. Results showed these two factors, when tested singly and in combination, to be significant and gave the equation:

$$Rch=0.1239\ Ussg+0.0956\ Lssg-0.0015(Ussg \cdot Lssg) -1.3855$$

with a standard error of estimate of 1.0 foot. The three independent variables explain most (96 percent) of the variation in road cut height. Two factors can be measured in the field and substituted directly in the above equations for calculating road cut height and embankment slope length, respectively. The latter value can then be used in the main regression equation. However, unless the proposed road is likely to traverse the crest of a ridge or the base of a well-defined U-shaped canyon, the Ussg and Lssg can be considered equal and can then be referred to as the average side slope gradient.

9/ Haupt, *op. cit.*

APPENDIX II

Reliability of the Equation Estimates

Before using the main equation, it is essential that the forest manager recognize its reliability. Theoretically, the equation will only forecast close estimates of the actual sediment flow distances that may occur. While one-half of the estimates probably will not be exceeded by actual distances, by the laws of chance an equal number probably will. For greater protection the forest manager should reduce the number that will be exceeded. He can do this by adding to the predicted values "one standard error of estimate" determined by the equation. One standard error of estimate is defined as the standard deviation of individuals around the regression line. For this equation the error of estimate or "safety margin" equals 47 feet. Thus when the safety margin is added to each of the estimated values probably only one out of six of the actual sediment flows that occur below roads will ever exceed the adjusted estimates. With the safety margin added, the protective strip required for trapping sediment will be wider, and the chances that the sediment will not span the protective strip under severe runoff conditions will be increased.