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SITE FACTOR VARIATIONS AND RESPONSES IN TEMPORARY FOREST TYPES IN NORTHERN IDAHO¹

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INTRODUCTION

The object of the study was to analyze and evaluate the environmental factors which govern the progressional stages of the secondary forest succession in northern Idaho.

When this study began much uncertainty existed regarding the distribution of trees and forest types in relation to temperature, precipitation, and evaporation and regarding their soil moisture and nutrient requirements in this region. Little was definitely known of the conditions which favored good growth and form of trees, or what gave rise to pure as distinguished from mixed stands. Furthermore, more exact and dependable information was urgently needed in connection with timber sale operations, reforestation practice, land utilization, and forest management generally.

For these reasons studies were begun as early as 1912 with a view to obtaining data on the factors of air temperature, humidity, wind movement, and evaporation, and on the more important physical and chemical characteristics of the soil. The measurements of the various climatic factors, and of soil moisture and soil temperature were begun in 1911 and cover a period of 5 years. The study also included the records of germination and survival of native species from 1913 to 1917 at the points where the site factors were studied. Data were also obtained on responses of native nursery-grown trees installed at these locations, which cover a period of twenty years.

The entire project was approved as part of the research program of the Priest River Forest Experiment Station. In 1936 all of the data obtained were collected and written up as a thesis required for the degree of Doctor of Philosophy at Iowa State College.

It must be recognized that in studies of plant growth and development quantitative standards are yet in the making; that the influence of variable intensities of the environmental factors is not fully understood, and that definite responses of the plant are difficult to establish. Factors of site become controlling according to their duration, summation or extremes; and any individual factor either of climatic or edaphic origin may of itself become limiting to one or more species. The investigator must therefore endeavor to learn what influences seem to be dominant or in what phase or period in the plant's development the individual external factor assumes a leading or limiting influence, and what combinations or summations of the environmental entities become significant, both for single species and for groups or associations.

The writer is much indebted to Raphael Zon and Donald R. Brewster, whose inspiration and encouragement stimulated the initiation and continua-

tion of this project; to those who while Forest Assistants in the U. S. Forest Service helped with the daily records and earlier tabulations, particularly Ernest C. Rogers, C. C. Delavan and Dr. T. S. Hansen; and to Dr. J. M. Aikman, of Iowa State College, for his help in the organization of the material and the preparation of the manuscript.

REVIEW OF LITERATURE

A review of the literature bearing on this problem and related subjects reveals that most of the previous studies of site factors or of correlations of these factors with germination, survival, and growth of trees are incomplete. In some studies only climatic factors are considered; in others only edaphic components. The magnitude of the task involved in a complete study of all factors for any one location no doubt explains the limited number of complete investigations.

In a review of the literature on this subject it is important to consider papers which treat of coniferous forests. An effort has been made to group these papers under two heads: those dealing with climatic and those dealing with edaphic factors. In case of the latter the object has been here to dwell on those which indicate a trend and a progress toward our present knowledge in this field.

Nichols (1924) suggests that the environment of any organism may be described as the sum total, or rather as the resultant, of all the external conditions which act upon it. He considers that the influence of the environment upon a plant is expressed most clearly in terms of limiting factors, but that when a process or reaction which is dependent upon the combined activity of several factors tends to be limited by some particular factor, the limiting effect of this factor may be compensated by the relatively favorable effect of other factors. Obvious compensations exhibited are need for increased light or a decreased demand for moisture due to low temperature.

Livingston (1921) emphasized duration and magnitude of the factors when he classified them as exponential indices, and proposed the use of the ratio of the sum of the physiological indices to the sum of the exponential indices, and also of precipitation-evaporation ratios and temperature-evaporation indices.

Palmgren (1926) reminds us that not only the manner of reactions, but also the interactions of factors within their effective limits must be noted. He states that various phytogeographical factors may cooperate in various ways, in various combinations at various times, and, first and foremost, in different relative strengths. Although many factors quite naturally interact intimately and regularly, others influence each other under certain conditions only. In dealing with a given relation in which plants may occur, he says we are often able to point out definite factors which clearly enough have served as absolutely necessary conditions; and when we perceive a particular

mode of occurrence always reappearing under apparently similar circumstances, we may feel justified in considering the phenomena as illustrating a law.

Lundegardh (1925) considers that every stage in the development of a plant not only has its own optimum temperature, but that the position of this optimum is influenced by light, nutrients, and other factors, even the vigor or the reserve of a plant itself. Lethal temperatures are raised or lowered by the influence of other factors of life and growth, and the important physiological processes do not increase regularly with increase or decrease in value of environmental factors.

For the territory of the Rocky Mountains we have reports by Bates (1924), Larsen (1930), and Pearson (1931) who set forth the ranges and requirements in temperature and moisture of most arborescent species. The prairies of northern Idaho may be said to approximate a growing season of 235 days; 201 days to 241 days for western yellow pine; 165 to 201 days for western white pine; 110 to 145 for the sub-alpine trees of Engelmann spruce and alpine fir. The lower limits of annual precipitation for these associations are, in order, given as 9, 15, 22, and 26 inches.

Robbins (1910) has expressed approximate frostless periods of 5 months and 6 days for the desert, 3 months and 6 days for spruce forests. Frostless periods, however, reveal quantitative requirements of native species much less definitely than temperatures above 43 degrees F.

Pearson (1931) minimizes the value of determining the length of the growing season upon the basis of frost-free nights, since some species make their major growth in late spring, when frosts occur almost every night, and most of the native trees and shrubs in Arizona cease vegetative growth long before the first freeze.

Münch (1915) shows that the heat of the surface soil varies with its dryness, looseness, and color. The highest temperature of moist topsoil recorded was 100.4° F., the highest temperature of similar soil when thoroughly dry reached 148.4° F. Damage to seedlings by lesions took place at temperatures of 140° F.

Similar studies have been made with native evergreens by Korstian and Fetherolf (1921), Toumey and Neethling (1923), and Baker (1929). It appears that the maximum surface or near-surface heats tolerated are: Engelmann spruce, 108° F.; western red cedar, 96; grand fir, 123; and Douglas fir, 131. The increased resistance to injury by extreme heat is due to a thickened epidermis, increase in xylem material and endodermis. Bates (1924) believes that the resistance of evergreen seedlings to heat injury varies inversely as their resistance to transpiration. He lists the heat tolerance in this order: lodgepole pine, western yellow pine, Engelmann spruce, and Douglas fir.

The writer believes that a decrease in direct or diffused sunlight may

easily become a limiting factor in the establishment of evergreen seedlings, especially under cover of other trees or shrubs or in the presence of dense herbaceous vegetation. Nevertheless, he is quite certain that the trees concerned in this investigation possess ability to tolerate shade in different degrees and that this ability expresses itself in seedlings as well as in mature trees. The relative light requirements of the seedlings are often in themselves responsible for the mortality of naturally sown seedlings in various locations within forest areas. In support of these statements the investigations of Burns (1923), Shirley (1929), and many earlier workers can be cited.

Bates (1929) in listing the minimum light requirements for six Rocky Mountain species, gives Engelmann spruce 1.1 percent and piñon pine 6.3 percent. He considers that the seedlings differed in their water requirements inversely as their photosynthetic activity under low light intensities. However, since only 2 percent or less of the total water transported upward in the plant is used in carbon assimilation, it is difficult to believe that such small differences are significant.

Toumey and Kienholz (1931) showed that the competition for soil moisture by underground roots of trees is an important cause of decreased growth and even of failure of new seedlings. The soil moisture in the trenched plot was several times greater than in the plot where the roots which entered from the surrounding trees had not been severed.

A study of rainfall is of importance chiefly as it affects available soil moisture. In general, an increase in atmospheric moisture results in greater amounts of available soil moisture and a more hydrophytic vegetation. Sometimes even under abundant rainfall and suitable air temperature periodic deficiencies of water in the soil may, because of the loose structure of the soil, give rise to a xerophytic vegetation. The different degrees of precipitation under which the Rocky Mountain trees grow have been set forth in the papers by Pearson, Bates, and Larsen referred to above.

But mere rainfall data do not tell the whole story, for the depth and duration of snow cover bear a direct relation to soil temperature and the length of the active growing season. Measurements of depth of snow cover prevailing in the northern Rocky Mountain forests, as given by Larsen (1930) show 17 to 50 inches for the prairies, 37 to 76 inches for western yellow pine, 66 to 207 inches for western white pine and associates, and over 200 inches in the spruce-lodgepole pine forests at higher elevations. Delayed melting of the snow cover supplies water to the soil which thus becomes available for the beginning and maintenance of growth in the spring and early summer months. Furthermore, the snow blanket reduces soil temperature extremes and provides protection to bacterial life and to new seedlings and young trees.

Weaver (1914) studied the evaporation in certain northern Rocky Mountain evergreen communities. He gave the cedar association, which is fairly

close to the Idaho cedar-hemlock-white fir habitat, 0.55 percent greater evaporation than that given by Fuller (1912) for the eastern hardwoods of beech-maple. Evaporation in the larch-fir association in Idaho was 20 percent greater than in the cedar. The prairie association showed 150 percent greater evaporation than the cedar forest.

Researches dealing with edaphic factors are many but scattered. Since practically no such research has been done in the Rocky Mountains, we must reason from principles established elsewhere. In this connection it becomes desirable to consider the soil structure, its organic constituents, bacterial and colloidal properties, and their influence on the temperature and moisture relations; also the chemical elements present, particularly nitrogen, phosphorus and calcium, as well as the microorganisms and the effect of these on humus decomposition, acidity, and alkalinity.

Only very recently have major soil groups been proposed for the world by Glinka (1927), who placed the gray forest soils and podzols in the incomplete or endodynamomorphic category.

Burger (1929) and Miller (1923) have investigated forest soils from the standpoint of porosity and water-holding capacity, Burger in Switzerland and Miller in Michigan. Their investigations reveal that forest soils contain more organic material, especially in the upper 6 inches, and are more porous and absorbent than field soils. The ability of bare soil to absorb water is generally less at the surface than in the lower layers. Burger reports absorption of 63.6 percent of their weight for forest soils and only 8.8 percent for grassland soils. Absorption naturally varies greatly according to the type of grass present and the degree of its use. Stewart (1933) has shown that bluegrass pasture soil in the United States ranks not far below forest soils in pore space.

Buckingham (1907) stated that movement of moisture through a column of dry soil probably occurs as a result of diffusion, and that the loss thus occasioned is proportional to the square of the porosity.

Caldwell (1913) pointed out that the reduction of the water content to the point of permanent wilting is the resultant of the action of transpiration versus root absorption. When the water supply fails, there remains in the soil a quantity which is definitely related to the physical constant of the soil.

Heinrich (1875) may be said to have begun our concept of soil structure, root and water relations. He said "Neither the different cultivated plants nor those designated as swamp or sand plants differ in their ability to extract water from the soil." Briggs and Shantz (1912) came to a similar conclusion. Small differences which occur in this respect are exhibited by plant groups such as grain crops, root crops, and weeds. Craib (1929) added that this physical constant or wilting coefficient is in a large measure dependent upon the colloidal properties of soil; and Haig (1929) considered that height growth of the trees which he studied is definitely linked with the colloidal

properties of forest soil. This problem naturally admits of further investigation, which should reveal more definitely what chemical and microbiological properties influence the colloidal properties.

Stiles (1914) stated that the water content links the physical and chemical characters of the soil together, granted that the soil structure controls the water present. He accordingly proposed a humidity coefficient which could be used in the classification of forest soils.

Falconer and Beal (1933) concluded that excess of moisture in the soil tends to favor anaerobic activity; optimum moisture, aerobic bacterial activity. A turn in either direction may be determined by fineness or coarseness of the soil. Leaf litter under evergreen species decomposes at variable rates, and all decomposition activities on the forest floor are hastened by increase in temperature, provided moisture is sufficient.

It appears from numerous investigations, that the activity of microorganisms depends upon the amount of humus and suitable atmospheric factors, and that denitrification does not proceed satisfactorily unless there exist suitable bases which may neutralize the acids originating from the humus. Bokor (1929) recommends a close study of the microflora of forest soils. Such a study presents a more complicated problem in forests than in agricultural soils. In forest soils a greater emphasis is placed upon the carbon-nitrogen ratio and the humus and lime contents.

Falckenstein (1911), Hicock, *et al.* (1931), Waksman, Tenny and Stevens (1928), conclude that the rate of height growth of trees is definitely related to nitrogen content of the soil and the ammonia resulting from action of the microflora on sugars and hemicelluloses present. They consider that in acid soils fungi are the only agents causing such decomposition, aerobic conditions being essential. In neutral or nearly neutral soils the moisture factor is most important in determining the nature of the organisms which develop, the activities of Actinomycetes being limited to dry soils.

Süchting (1927) claims that the bases are necessary in maintaining soil quality; and that in order to improve impoverished soils, acid must be removed and the missing ingredients supplied. Schutze as early as 1871 demonstrated that in German forests phosphorus, calcium, manganese, potassium, and sodium all increase in quantity in soils on the better sites.

Gaarder and Alvsaker (1938) maintain that, in the western part of Norway particularly, nitrogen content is the deciding factor for plants. This element is required chiefly by microorganisms, especially in the process of decomposing humus and litter; and unless the bed-rock and subsoil supply the necessary bases to hold nitrogen in place, heavy rainwater will cause it to leach out. If leaching takes place, the inevitable result is a strongly acid soil. Therefore the mineral components of bed-rock and subsoil are of paramount importance.

Kruedener (1927) on the other hand, states that the forest type classifica-

tion is one of soil moisture, aeration, and character of the upper organic horizon combined with the petrographic, physico-mechanical groups.

It is held by some authors that soil may be mellowed or neutralized by burning, which no doubt is of value in certain northern locations. Fowers and Stephenson (1934) report that the amount of nitrification in forest soils is stimulated by burning, which results in liberation of basic ash materials and thus increases soluble mineral nutrients for some time after the fire. Since burning destroys the top and surface organic matter, repeated and continuous burning becomes harmful. Hesselman (1918) attributed the successful regeneration of spruce in northern Sweden to nitrification resulting from forest fires, for in pure coniferous forests heavy raw humus renders electrolytes immobile and creates high acidity in the upper layers. This condition is unfavorable for bacterial activity and results in decreased nitrification. The release of mineral substances from ash in the form of soluble salts after the fire assists in nitrification. Hesselman concludes: "As a result of this presentation I am by no means an opponent to burning. I assume, on the contrary, that fire has been an important means of retarding the formation of raw humus. . . . Natural regeneration takes place in the absence of this action, but vastly more slowly."

Barnette and Hester (1930) conclude that the quantities of potassium and other ash constituents are somewhat increased by burning. A low pH concentration on burned areas is also believed to be due to burning and the resulting addition of ashes. Burning injured the colloidal and physical properties and later the chemical. Hackmann (1931) discredits the value of nitrogen, lime, and potassium fertilizers for forest soils and states that phosphorus fertilizers have greater value, basic slag being particularly effective. Phosphorus fertilizers, he claims, give best results on soils with pH values from 4.5 to 6.5.

Tamm (1920) writes that in podzolization under evergreen forests in the colder regions aerobic conditions usually exist and iron may serve as a sol, since it is protected by organic colloids. As a result of leaching of bases, the horizon of alluviation becomes enriched with electrolytes, which cause precipitation of iron and aluminum. Iron and aluminum then serve as a cementing material for incrustation, leading to a hardpan formation.

In some studies in this field the belief has been advanced that the type of vegetation on the terrain plays no small part in soil amelioration or acidification. Diebold (1935), however, holds that soils play a greater role than trees in the formation of humus layers. He states that the poorest type of humus layers is found under a natural association of hemlock and white pine on well to moderately drained nonlimestone Till soils and their steep phases; and that the very best type of humus is developed by hardwoods on limestone soils.

Chandler (1937) has stated that hemlock forests tend to deplete bases

present in the surface soil and cause it to become more acid. On the basis of studies carried out in the Adirondacks, Heimburger (1934) stated that the mineral soils showed practically no correlation between lime content and productivity of the types. The "richer" types had generally a higher lime content than the poorer types, but humus in some of the richer types was very acid and showed little relation to productivity. He concluded that in this region forest types were governed more by climate, geologic formation, topography, and drainage.

Whitfield (1933), who obtained data on the acidity of soils in given altitudinal zones in Colorado, gives for the plains a pH varying from 6.52 to 6.99, for the intermediate montane zone 7.41 to 7.69, and for the alpine zone from 5.25 to 5.88. In the plains and the alpine zones the soil at 12-inch depth was more acid than the 6-inch and surface layers, in the intermediate montane zone the surface was slightly more acid (7.41) than the 12-inch samples (7.69).

According to Turner (1938) there are certain definite mathematical correlations between drainage, soil characters, and height growth of shortleaf and loblolly pines; the best correlation was expressed by the slope gradients between 3.5 and 22 percent; the next best correlation was expressed by depth of the B-1 Horizon; and a rather insignificant correlation existed between the clay content in the B-2 Horizon and height growth. Turner concluded that the interaction of several factors is more influential than the effects of any single factor in determining the rate of height growth.

Turner (1936) observes that site indices (based on height growth of trees) could well be correlated with quantitative group combinations of factors as summarized in a specific soil, with a specific slope, but not with any one factor or grade of factors.

LOCATION AND METHODS

The Priest River Experiment Station is situated in the pan-handle of northern Idaho, in the north and south trending Priest River Valley within the Kaniksu National Forest. The general elevation of the valley floor at this point is 2,300 feet above sea level. On the west side the hills are less than 2 miles distant and rise about 2,000 feet above the valley; on the east side the divide rises to a total elevation of 6,000 feet and is 4 to 5 miles distant. The region is uniformly covered with dense forests except for a sloping mountain meadow on the eastern ridge and some scattered patches of cleared land along the main river and its tributaries.

The different forest types occur in altitudinal zones, beginning with a lower belt of western yellow pine (*Pinus ponderosa*), which in places may reach an elevation of 4,000 feet. This consociation usually gives way at the upper border to the more mesic species of western white pine (*Pinus monticola*), grand fir (*Abies grandis*), western red cedar (*Thuja plicata*), and

western hemlock (*Tsuga heterophylla*). Other species frequenting this mixture are western larch (*Larix occidentalis*), Douglas fir (*Pseudotsuga taxifolia*), and lodgepole pine (*Pinus contorta* var. *Murrayana*). At an elevation of 5,000 to 6,000 feet the subalpine forests begin, consisting of Engelmann spruce (*Picea Engelmannii*), mountain hemlock (*Tsuga mertensiana*), alpine fir (*Abies lasiocarpa*), and whitebark pine (*Pinus albicaulis*).

The western yellow pine is comparatively pure, especially on the warmer sites. It sometimes mixes with Douglas fir and lodgepole pine and western larch on locations with more soil moisture. Within the intermediate belt the western hemlock and the cedar are the most shade-enduring and permanent species, whereas Douglas fir, western larch, and western white pine are temporary. Western white pine occurs chiefly on the northerly slopes, moist benches and flats; and is most abundant on soils which are eventually claimed by the cedar-hemlock association. Western larch appears most often on sandy bench land or on lower slopes, and Douglas fir grows more often on steep slopes, especially toward the upper parts. Engelmann spruce and alpine fir which are naturally at home above the cedar-hemlock zone are sometimes found along the cool creek bottoms or deep sheltered valleys. Whitebark pine occurs on the more exposed sites within the sub-alpine zone.

This investigation is concerned with the successional stages of development within the central belt and the progression toward the final climax, commonly called the cedar-hemlock association.

MEASURING CLIMATIC FACTORS

Three main meteorological stations were used in this study: Station 1, on the flat in the larch-fir type; Station 2, on a southwest aspect in western yellow pine; and Station 3, on a northeast slope in a forest composed principally of white pine. There were substations with shorter records: No. 4, on a low flat in the cedar-hemlock-white pine type; 2a, b and c, on steep phase exposed western yellow pine sites; and 3a, on a steep northwest slope in Douglas fir. (See Figs. 1, 2 and 3.)

The station on the flat, Station 1, which served as a control for the others, was placed within a clearing made partly by fire and partly by axe on a sandy bench approximately 100 feet above the main river. This plain has been formed by glacial lake deposits composed chiefly of granitic sand. The land has been burned over twice, about 70 and 40 years before the inauguration of the experiment, and has since been slowly restocking with native trees, chiefly western larch. The earlier fire killed the mature timber and the later one cut big holes in the second growth. Much of the dead and down larger material had been removed for fire wood; and when the experiments were begun, the remnant of debris was removed in order to make room for the station and the various planting tests. Some shrub vegetation has gained a foothold subsequent to the fires, the principal species being mountain balm (*Ceanothus velutinus*), kinnikinnick (*Arctostaphylos uva-ursi*), nine-

bark (*Physocarpus malveceus*), june berry (*Amelanchier alnifolia*), goat brush (*Pachystima myrsinitis*), and *Spiraea lucida*. (Fig. 1A).

Station 2 is on a medium-steep southwest aspect directly north from the flat. The forest consisted chiefly of mature, but very scattered, trees of western yellow pine and a younger understory of mixed yellow pine and Douglas fir. The fire history, destruction and later restocking have developed here along the same lines as on the flat. In addition there existed many clumps of shrubs, chiefly of willow (*Salix scouleriana*), ocean spray (*Holodiscus dumosus*), mountain balm (*Ceanothus velutinus* and *C. sanguineus*), mock orange (*Philadelphus lewesii*), and ninebark (*Physocarpus malveceus*). (Fig. 1B).

The trees and shrubs combined constitute a topcover of about 50 percent, but of irregular occurrence. In the sub-dominant layer were pine grass

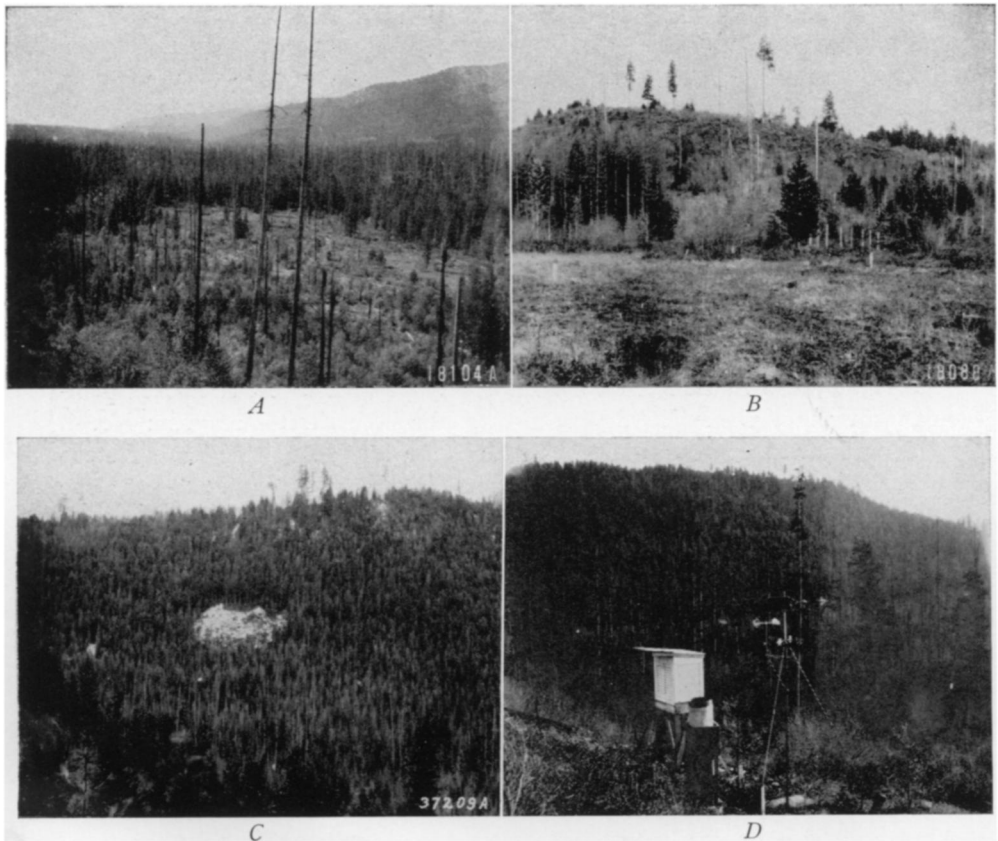


FIG. 1. A. View south over Priest River Valley. Benton Flat location for Station 1. B. Southwest slope, location for southwest slope yellow pine and location for Station 2. C. Northeast aspect in white pine and location for Station 3 in clearing. D. Northwest aspect in Douglas fir and location for Station 3a. (Near view shows meteorological set-up for Station 2.)

(*Calamagrostis suksdorfii*), alum root (*Heuchera bracteata*), Oregon grape (*Berberis aquifolium*), Indian paint brush (*Castilleja peteolata*), and lupine (*Lupinus ornatus*).

At Station 2 fires, heat and wind, typical of western slopes, had reduced the humus layer and favored leaching of the soil, which had resulted in the appearance of shaly fragments near the surface and the absence of any appreciable amount of dark or loamy soil in the A horizon.

The slope reserved for Station 3 is on a 60 percent northeast aspect across the valley of Benton Creek to the east from Station 2. The crest of the secondary ridge is 600 feet above the main valley bottom. There was present on this slope a well developed 70-year-old stand of western white pine, with some western larch and other species. Toward the top of the ridge the stand was chiefly Douglas fir, and from the middle slope downward there was an understory of cedar and hemlock. Evidently the second fire, which 40 years earlier had caused destruction in the second growth on the flat and on the southwest slope, did no damage whatever on this site. (Fig. 1C).

On this northerly gradient the soil was 12 to 18 inches deep and loamy with a thick layer of humus and dead needles, but with abundant angular shale fragments which no doubt have become mixed during periods of soil slipping. The reddish brown soil rested directly on a bedrock of shale.

Only under the trees where the light was much reduced were found various sub-dominant evergreens, such as twinflower, *Linnaea borealis*, *Cornus canadensis*, gold thread, *Tiarella trifoliata*; Clintonia, *Clintonia uniflora*, and wintergreen, *Pyrola bracteata*. On this aspect there was neither natural

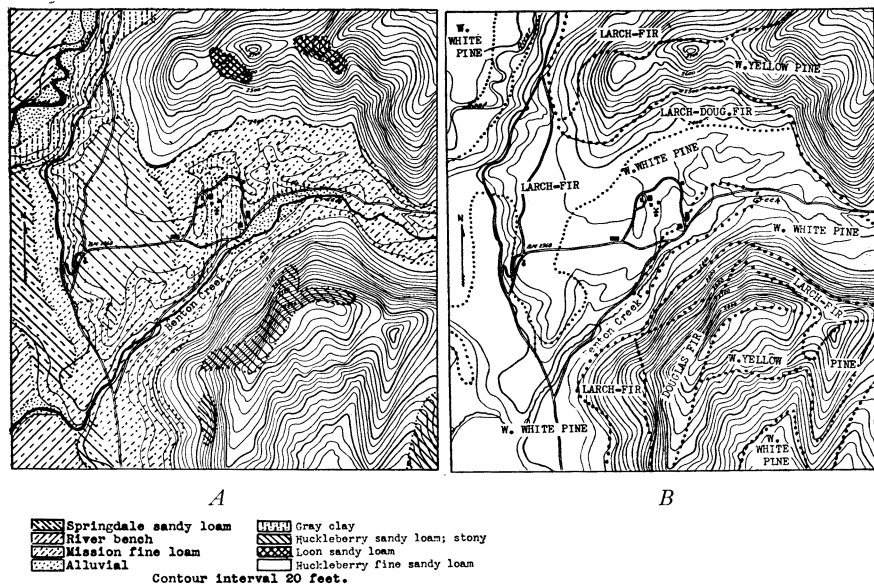


FIG. 2. A. Topography and soil types of the area. B. Temporary forest types.

clearing nor a shrubby association. A one-acre clearing in the young forest was therefore made. (Fig. 1C).

These three locations provided representative sites for the installation of meteorological instruments, soil sampling and the seeding and planting tests.

Sub-station 4 was within a clearing in the 70-year old white pine and larch on a bench having the same elevation as the flat referred to, but nearer Benton Creek. For that reason the soil was silty and compact, quite different from that at Station 1. There was a second growth of western white pine and western larch with an abundant understory of cedar and hemlock. The remaining dead trees and the down timber indicated that the original stand prior to the fire 70 years earlier had contained considerable cedar, with some white pine and western larch. (Fig. 3A).

Observations were also made during the growing season of 1915 at another point where the site appeared more extreme than on the southwest

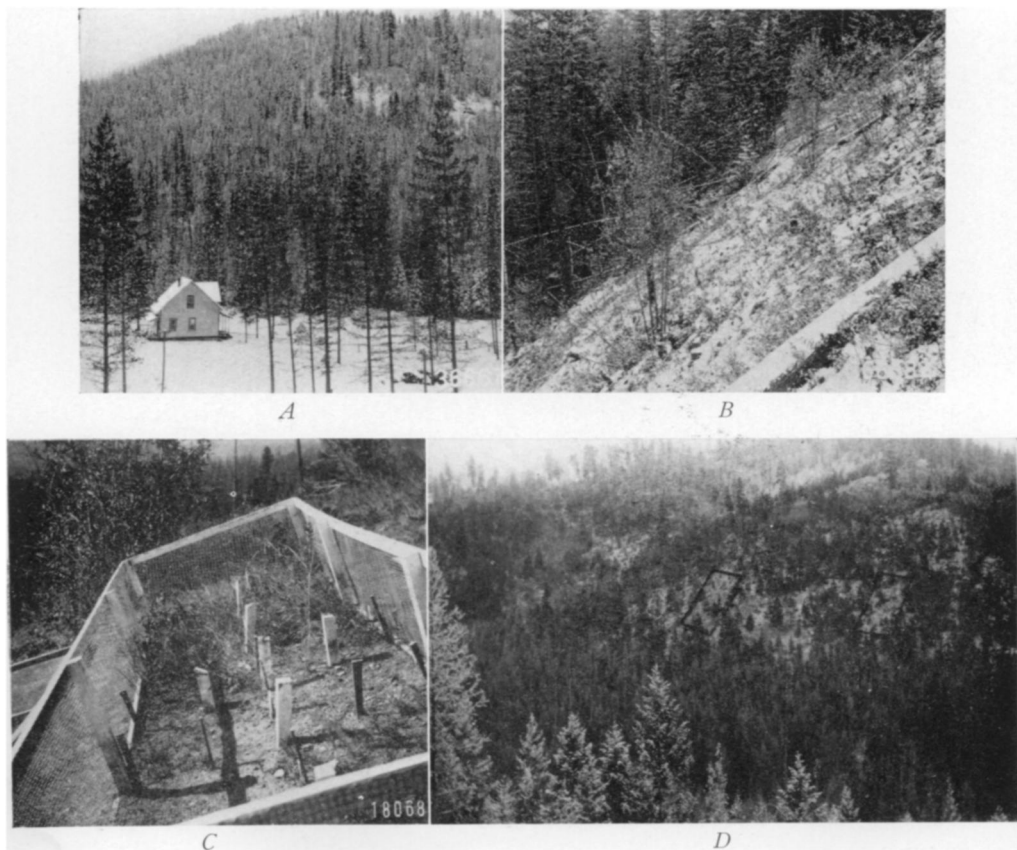


FIG. 3. *A.* Laboratory building and the steep northwest aspect; location of sub-Station 3a. *B.* Details of ground cover and young forest at Station 3 on northeast aspect, 1914; before planting tests were installed. *C.* Seed bed near Station 2 on southwest aspect. The type used for seeding tests. *D.* Steep southerly aspects in open western yellow pine; locations of sub-Stations 2a, 2b, and 2c.

aspect; namely at 2a, on a steep westerly slope. (Fig. 3*D*). During 1915 records were also obtained at 3a, in pure Douglas fir second growth on a steep northwest aspect, on the same secondary ridge, but south from Station 3. (Fig. 3*A*). When the final soil samples were collected in 1932, each one of these sites was represented and several additional locations were chosen for sampling.

The meteorological equipment installed conformed to that used by the United States Weather Bureau. At each station were placed maximum and minimum thermometers of the standard make, a Robinson anemometer and an air thermograph. The stationary instruments were housed in a shelter of the standard pattern, 4.5 feet above the ground. (Fig. 1*D*). (A standard sling psychrometer was used at all of the stations. Each station was also provided with soil thermometers of the maximum and minimum type at the surface, and soil thermometers for readings at 6 and 12 inches below the surface.

In addition to this equipment the station on the flat, serving as a control, was provided with electric contacts for rainfall, sunshine and wind records on a two-magnet meteorograph. The readings of all the factors were made according to mountain time at 5:15 p.m. at Station 3 on the northeast slope, 5:45 p.m. at Station 2 on the southwest slope, and at 6:00 p.m. at Station 1 on the flat.

Air temperature records were obtained at each of the three main stations during the entire five years, and at Station 4 from 1914; and growing season temperature records are available for 1915 for the steep southwest slope (2a) and steep northwest slope (3a). In all cases standard maximum and minimum Weather Bureau pattern thermometers and Friez thermographs were used.

Although all of the hourly temperature records for the entire 5-year period have been tabulated, the unavoidably voluminous data are largely omitted from this report.

Comparative observations on the amount of light within the plant communities were confined merely to a few tests with a Clements Photometer during the growing season of 1913.

Measurements of precipitation embraced records of rainfall and snowfall and of the depth of snow on the ground each day during the season of snowfall, made by use of the standard United States Weather Bureau gauges, checked for durations and intensities by the electric tipping bucket at Station 1.

At the control station on the flat a large Marvin shielded rain and snow gauge was used. This gauge was provided with a spring scale for weighing the amount of rain or snow for each day. The unmelted snow portion was carried into the laboratory where it was melted and carefully measured. Depth of new snow was obtained with the rainfall scale on a canvas mat.

The depth of accumulated snow on the ground was read on the stationary vertical scales at each station.

Relative humidity was measured with a standard sling psychrometer. The pressure column for 27 inches was used in determining relative humidity. No hygrographs were employed at any time. Naturally the low humidity readings which are obtained in the afternoon and the evaporation records carry a much greater significance than readings for the morning hours when temperatures are low and humidity high.

A Robinson cup anemometer mounted 9 feet above the ground at each station provided very reliable wind velocity data. At the control station an electrical connection was made to the office meteorograph, but the hourly tabulated records are omitted because there are no comparisons with the other two sites. (Fig. 1D).

The evaporation records, which began in 1914, were made on free water surfaces. From the middle of the summer of 1916, Livingston porous cup atmometers were in use. A comparison of the two methods was continued for some time during 1916.

The free water surface was that of an empty 5-gallon gasoline can set in the ground and painted black and protected by 1-inch poultry netting over the top. Each day the water levels were measured with the rain gauge stick and the water refilled to a line 1 inch below the edge of the can. The amount of rainfall naturally had to be considered in listing the total evaporation for the 24 hours.

Livingston porous cup atmometers were set in the ground to the neck of the jar, and the cup itself was protected with poultry netting.

MEASURING EDAPHIC FACTORS

The first test of the soils at the different stations dates back to 1915 and comprises mechanical and physical analyses, with ordinary standard soil sieves and laboratory tubes. Most of these early data have been discarded in favor of the more exact analysis of 1932.

The more complete study of soil samples, which included mechanical, physical, and chemical properties, was begun in 1932 and completed in the soils laboratory at Iowa State College. Measurements were made of soil temperature and soil moisture relations in the field during several growing seasons from 1912 to 1916.

Soil moisture determinations are all based on the dry weight; sampling was done by means of a geotome in the undisturbed soil during 1912, 1913, and 1914 and with soil augers in the soil wells during 1916 and 1917. The depths represented are: surface inch; 1 to 6 inches; 6 to 12 inches. The duplicate samples were dried in an oven to constant weight at temperatures not above 110° F.

During 1915 and 1916 sifted local soil was used in one well and sifted sandy loam from station 1 in another. The object in this procedure was to

study more closely the influence of aspect itself on the loss of moisture from the soil. When soil was removed from the wells in sampling, it was replaced by the same kind.

The data on soil temperature were obtained by daily readings at the three main stations from the beginning of the growing season 1913 until the end of 1916. Records were also taken at the sub-stations 2a and 3a during the growing season of 1915. The points at which readings were made are: surface inch, 6 inches and 12 inches. Some records were also obtained during 1912 and 1913 at 24-inch depths.

Surface readings were obtained with standard maximum mercurial and minimum alcoholic thermometers, the bulbs being set within the soil and the rest of the instrument covered with a cedar shingle.

For deeper readings, the mercurial thermometers were set vertical in contact with the ground and within 2 by 2 inch hollow wooden tubes so that the upper end was attached by a string to a wooden plug which closed the bore in the wood. For the 24-inch depth, permanently set soil thermometers were employed.

Some records for 6, 12, and 24 inch depths were obtained during the entire winter of 1915-16. (Fig. 8).

At each point where soil samples were taken in 1932, a canvas was spread on the surface of the ground for mixing the soil. The upper layer of litter and undecomposed organic material was removed and discarded. The spade was then thrust down to a depth of about eight inches, lifting the soil. This was then placed in a heap on the canvas. Here about 50 pounds of soil, taken from four separate pits, were thoroughly mixed with the spade. From this mixture a 2 pound coffee can was filled, covered and shipped to Ames by express on the same day. Another smaller sample was obtained and put in aluminum soil cans and tested for field moisture conditions. (Table 8).

SOWING SEED OF NATIVE SPECIES

This part of the investigation was begun in 1913 by sowing seed of six different native evergreen species in duplicate series on the three main sites. At each of the three main stations there was one seedbed 4 by 12 feet with 12 sub-plots (Fig. 3c): bed A on the northeast aspect; bed C on the southwest; bed E on the flat.

Each was placed in position to obtain the maximum possible light for its particular location.

Each unit experiment consisted of two sets of six plots which measured 2 by 2 feet, or 4 square feet, for each individual test or kind of seed. Six plots in one end of each bed were located on natural undisturbed surface and without removing the grass or litter; at the other end were six plots on which the vegetation was removed by burning. Each plot contained a definite number of seed of a given species. (See Table 15).

Once each week during the first summer after sowing, counts were made

of germination and survival in each sub-plot. At this time the new seedlings were staked out with toothpicks of a given color for each month of germination. The seedlings which had died during the intervening days were removed and the cause of death noted, if determinable. Weekly soil moisture sampling was continued from the initiation of this experiment to the end of 1914, with other moisture determinations later.

In the spring of 1915 each plot which showed seedling survivors was thinned out to a uniform number for all plots so as to obviate competition. From this time until the end of 1917 spring, midsummer and fall counts and observations were made.

PLANTING TESTS

Planting tests were made on the three main sites during 1912, 1914, and 1915. These are described in Series A to D. All the planting was done by two-men crews, one man digging the hole with a mattock and the other setting and firming the plants carefully in the ground. Data on survival and growth and on causes of loss or damage were taken in the fall of 1913, 1914, 1916, 1917, 1919, and 1921, with final height measurements in 1932.

RESULTS

CLIMATIC FACTORS

AIR TEMPERATURE

The air temperature records have been summarized in Table 1 and shown graphically in Figs. 4a and 5. The data in Table 1 and Fig. 4a reveal that the maxima are higher on the southwest slope than at the other stations, but that the flat is not far below. The northeast slope takes the lower level; there seems to be an absence of hot weather on this aspect. Minimum temperatures at the three stations show much less spread than the maxima and are appreciably lower on the flat than elsewhere. The greatest temperature ranges are found on the flat and the smallest on the northeast slope. The absolute minima are: -29.5° F. on the flat; -20.0 on the southwest; and -17.5 on the northeast. The lowest monthly minima reached during the growth period were 39.32 , 43.4 and 44.2° F. in the order given.

TABLE 1. SUMMARIES OF MAXIMUM AND MINIMUM AIR TEMPERATURES 1912-1916

Datum	Period	Station 1 Flat	Station 2 SW Slope	Station 3 NE Slope
Averages of monthly maxima.....	Growth	73.5	74.5	70.0
	Rest	42.5	43.7	41.8
Averages of monthly minima.....	Growth	39.2	43.4	44.2
	Rest	22.0	25.5	25.9
Means.....	Growth	56.2	58.9	57.1
	Rest	32.1	34.9	32.9
Average annual range.....		26.2	23.6	18.9
Absolute maxima.....		97.0	99.0	95.0
Absolute minima.....		-29.5	-20.5	-17.5
Extreme range.....		126.5	119.5	112.5

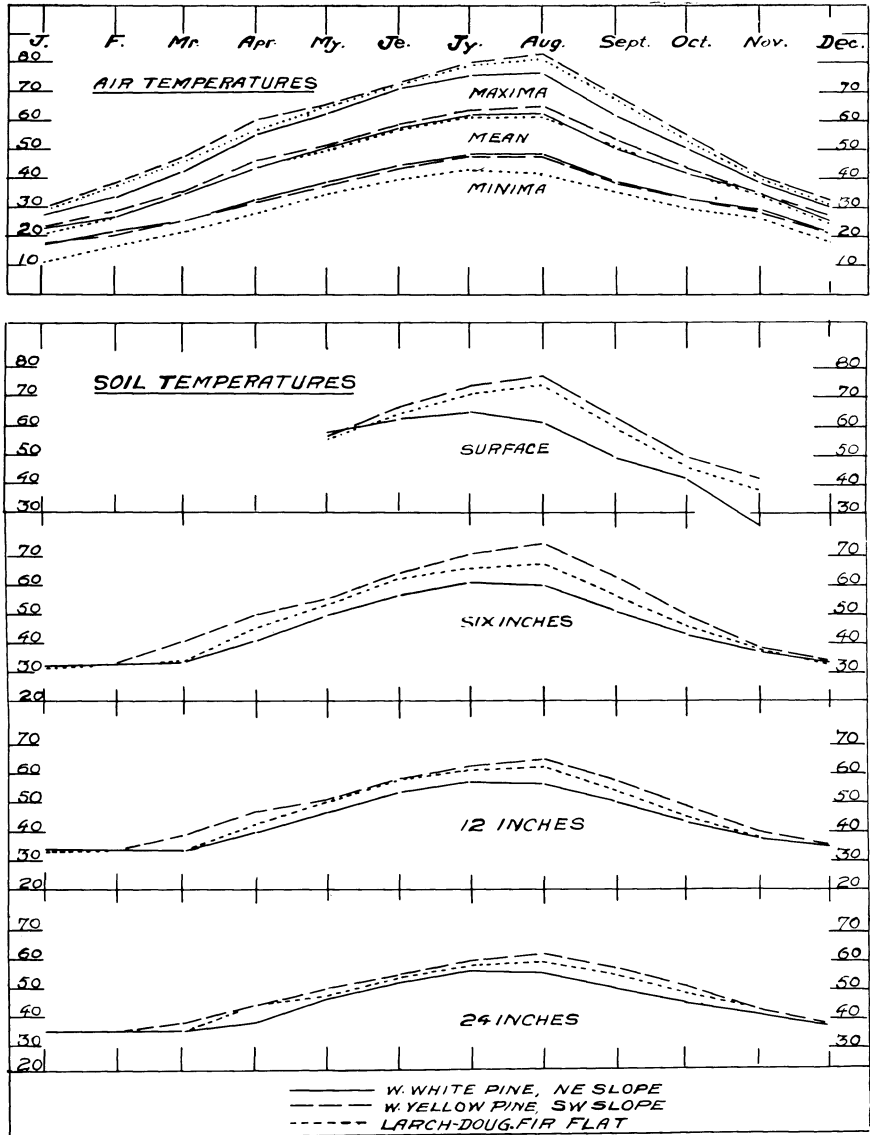


FIG. 4. Air and soil temperatures in degrees Fahrenheit by months.

The thermograph records given in Fig. 5, plotted according to the 2-hour periods, give typical daily oscillations for the three sites and the time at which the highest and the lowest air temperatures occur. From December until February, inclusive, the high points of temperature for all the stations is about 4 p.m., but from this time onward the maximum on the northeast moves forward to 2 p.m., and in August is highest at noon. The digression

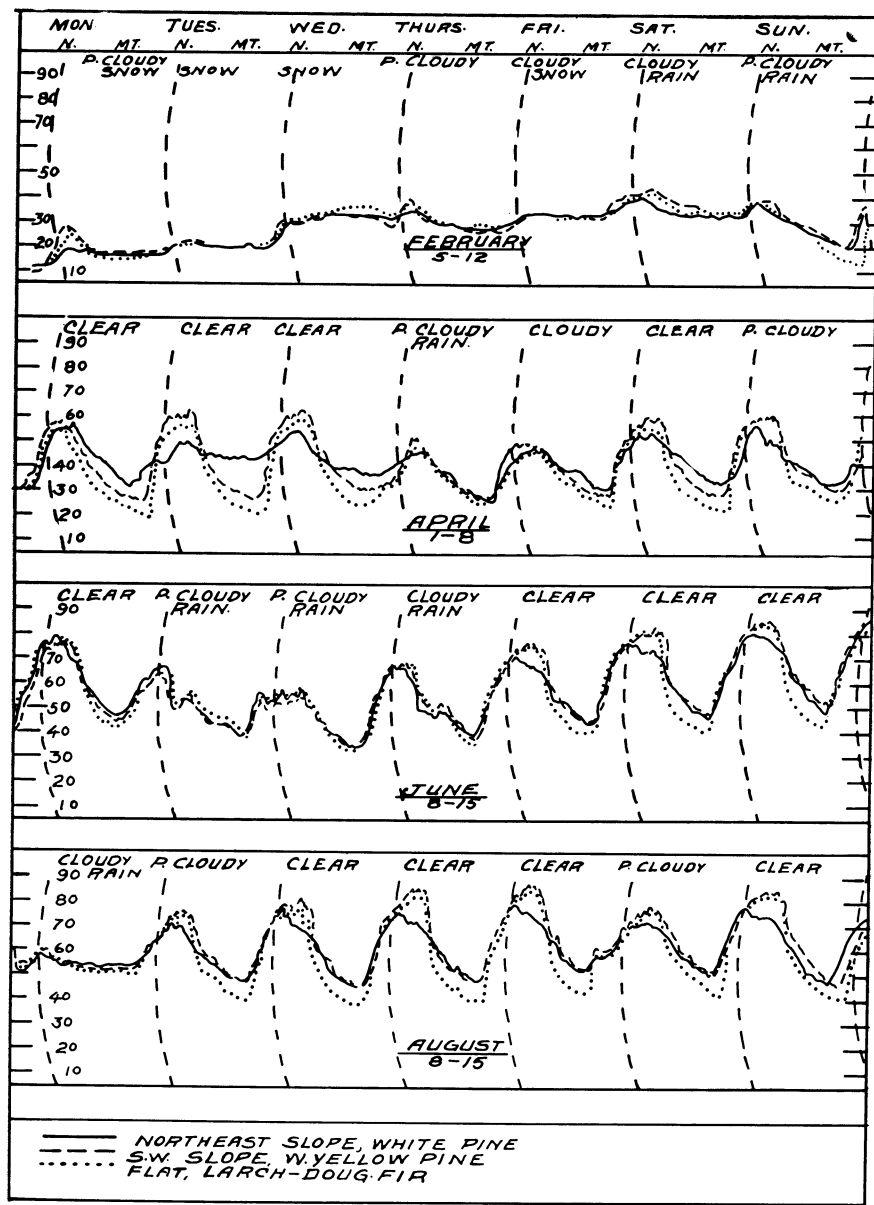


FIG. 5. Typical diurnal thermograph records for selected weeks in 1916.

at Station 3 is due to the position of the sun with respect to the slope and mountain form. At the other stations the extremes of temperature, wind, and relative humidity coincide better.

There is naturally at all the stations a greater diurnal fluctuation in sum-

mer than in winter; but the oscillations are much more pronounced on the flat than elsewhere, and the drop in the minima from midnight until the low point is reached in the morning is practically identical and much less sudden for the two slopes than for the flat. During the colder months, and particularly in cloudy weather, the tendency of the temperature curves is to converge and coincide.

In order to determine how air temperature differences affect the periods of warm, hot or cold days, on the several sites, the days having specific air temperatures of 32° F. and below, 32.0 to 40.0 and 40.1 to 50.0, were singled out. The resulting tabulation showed that the southwest slope actually had 70 more hours of effective temperature (above 43° F.) per growing season than the flat, and 75 more than the northeast slope. There are from 6 to 7 more warm, and as many more hot, days on the southwest slope than on the flat; there are no warm or hot days (above 59 and 72° F.) whatever on the northeast, and 13 more freezing days on the northeast than on the southwest slope. This comparison is based on the averages of the maxima and minima and not on the 2-hour tabulations.

In this region frosts have occurred during every month in the year, July and August not excepted. In general, no frost damage to the native vegetation has been noted during the summer months, but occasionally the tender shoots of Douglas fir and western white pine have shown injury by freezing on the flat in the spring. It was found very difficult to establish Douglas fir plantations on the unprotected sandy flat, because of frost injury to the tender shoots, which resulted in the formation of numerous stool shoots and no real advance in height growth. The white pine plantations showed frost injury during the spring of 1918, an unusually dry and cold season.

The total effect of the temperature variations is that the exposed slope corresponds to a lower forest zonation and the north aspect to a higher forest belt in the altitudinal scale. The high maxima recorded on the exposed aspects and the accompanying conditions in soil and surface are not tolerated by the more mesic species. The result is pure forest of western yellow pine or this species with Douglas fir and a complete absence of western white pine, cedar, hemlock, and white fir. The low temperature levels recorded for the growing season on the sandy flat are instrumental in preventing artificial establishment of Douglas fir.

LIGHT

Since light was not considered one of the controlling factors in the allocation of the species by site or slopes, very few light readings were obtained. Some observations made in the clearings near the three stations with the Clements photometer during the summer of 1913 are given below (Station 1 was used as the standard):

TABLE 2. LIGHT READINGS

Date	Station 1 Flat	Station 2 SW Slope	Station 3 NE Slope
May 2.....	1.00	0.89	0.44
July 5.....	1.00	0.70	0.25
August 27.....	1.00	1.00	0.47
Standard.....	1.00	Aver. 0.86	0.38

These few records show that even in the clearing on the northeast aspect light is reduced to about 38 percent of that recorded on the flat. Some readings were obtained also in the shade of shrubbery on the flat and southwest slope and under the young stands of trees on the northeast slope. These values referred to the same standard are in order 0.61; 0.61 and 0.03, with variations 0.30 to 0.80 on the flat; 0.70 to 1.00 on the southwest slope; and 0.02 to 0.05 on the northeast aspect.

To what extent light becomes a limiting factor or a cause in the local tree distribution is difficult to state. It is assumed with confidence that it is of practically no importance in the early establishment of all species except perhaps cedar and hemlock, which are supposed to possess chlorophyll rather sensitive to intense sunlight. These species are therefore at a disadvantage on exposed southerly slopes and are set back by sudden exposure occasioned by clearings. Later in life any western yellow pine trees which start on the north slopes are so weakened through scant foliage and slow growth that they succumb to competition of other trees during the period of most rapid height growth; that is, when the stand is from 40 to 80 years old. Even should individual western yellow pines survive this competition and become a part of the canopy of a mature stand, they would not be re-established because of lack of flowering and seeding.

The decreased amount of light for northerly slopes will retard development of intolerant trees which may seed and germinate on these sites, especially when mixed with more tolerant trees. Seed production itself is curtailed, under those conditions, even in case of the tolerant species.

RAINFALL

The records of precipitation and depth of snow are listed in Tables 3 and 4.

By reference to Table 3 we learn that there is very little difference in the total precipitation for the three sites. The average annual precipitation for the flat is 33.2 inches, for the southwestern slope 31.1 inches, and for the northeast slope 33.9 inches. There is less difference between the sites in the summer months than in the winter, and the greatest divergence occurs in November and March, during the windiest months, and at a time when much of the precipitation consists of snow which is carried about by the

TABLE 3. AVERAGE PRECIPITATION FOR A 12-MONTH PERIOD (BASED ON FIVE YEARS' DATA, 1912-1916)

	TOTAL PRECIPITATION (inches)		
	Control Flat	SW Slope	NE Slope
REST PERIOD			
October.....	2.8	2.6	2.8
November.....	5.6	5.3	5.7
December.....	2.9	2.7	3.1
January.....	4.2	3.9	4.2
February.....	2.4	2.3	2.5
March.....	2.6	2.4	2.7
April.....	2.1	2.0	2.1
Average.....	22.6	21.2	23.1
GROWTH PERIOD			
May.....	2.7	2.5	2.7
June.....	2.6	2.5	2.7
July.....	2.1	1.9	2.1
August.....	1.0	0.9	1.1
September.....	2.2	2.1	2.2
Average.....	10.6	9.9	10.8
Year.....	33.2	31.1	33.9

wind, swept hurriedly past the most exposed places at a low angle to the rain gauge, and settles in eddies on the leeward slopes. The summer differences are caused chiefly by the wind and are possibly augmented by evaporation. Since these differences are very small, and since sufficient moisture falls on all three sites to maintain a good stand of western white pine if other factors are favorable, precipitation is evidently not the controlling factor. It is, however, of great importance in indicating that even greater differences may be expected in mountainous country with topographic features of a larger scale.

Although an equal amount of moisture is precipitated at all of the stations, some of this may not be available on the flat because of downward percolation in the porous soil. An even lesser quantity may become available for plants on the southwest slope because of rapid run-off and high evaporation. These conditions have produced less complete vegetative cover and insufficient humus on the southwest aspect. While there is, therefore, less loss of water by transpiration on the exposed slope than on sites with more profuse plant cover, it is nevertheless true that the scantiness of organic matter reduces the water-holding capacity of this site and the amount of available soil water.

In rating the ability of various species to survive on dry sites as seedlings, it is important to examine the time or duration of extremely low moisture conditions, as these are more critical than mere absolute minima. On the drier slopes western yellow pine may survive by virtue of a high resistance to low soil moisture. It is certain that both the western yellow pine and western larch possess marked advantages over the white pine, firs, cedar, and hemlock in a more rapidly developed tap root.

SNOWFALL AND SNOW COVER

Table 4 gives the 5-year record of the snow cover on the different sites. Often, the first snow of the fall remains on the ground both on the northeast and the flat, but melts on the southwest slope. In the spring, however, there is a fairly constant time interval in the date of disappearance of the snow cover on the three sites. The average date for the southwest slope is March 8; for the flat, March 24; and for the northeast slope, April 6. The duration of the snow cover on the northeast slope is thus 141 days, on the flat 128 days and on the southwest slope only 106 days. This difference occurs mainly in the spring. Three successive periods in depth of the snow cover also occur;

TABLE 4. AVERAGE DEPTH OF SNOW AT THE THREE STATIONS FOR THE FIVE-YEAR PERIOD—1912-1916

		DEPTH OF SNOW ON THE GROUND IN INCHES		
		Flat Larch-Douglas Fir	SW Slope Yellow Pine	NE Slope
October	15	0	0	0
October	31	0	0	0
November	15	1.5	1.5	2.2
November	30	8.4	5.5	8.8
December	15	9.3	5.5	9.4
December	31	18.1	9.2	19.1
January	15	25.1	18.5	27.0
January	31	27.3	16.9	27.8
February	15	26.8	16.5	30.1
February	28	24.2	6.1	24.8
March	15	18.2	0.3	21.3
March	31	7.2	0	12.7
April	15	0	0	1.0
April	30	0	0	0
Average		11.8	5.7	13.2
Length of Snow Cover (days)				
Average		128	107	141
Maximum		147	133	154
Average Date of Disappearance of Snow Cover				
		March 24	March 8	April 6

that of accumulation, that when evaporation and melting equals the precipitation, and that of melting. The first period ends January 15, with only slight differences in the depths at the three stations. The second period ends February 15. During the melting period marked differences in depths exist between the northeast and the southwest slopes. The difference in time of melting varies somewhat according to the depth, the time of the last heavy snowfall, and the kind of weather, but is in the main directly attributable to differences in air temperature, wind movement, and amount of insulation caused by aspects, character, composition and density of the forest.

The much shorter duration of the snow cover and its more shallow layer on the southwest aspect under western yellow pine than on the sites with

larch, fir, or white pine, is an important factor in lengthening the growing season for the western yellow pine and in giving greater protection to soils and seedlings under white pine and more mesophytic trees.

RELATIVE HUMIDITY

By reference to Table 5 and Fig. 6 it is seen that the driest air conditions exist on the southwest aspect, and the most humid on the northeast. This holds true for averages and extremes, although differences in the minima

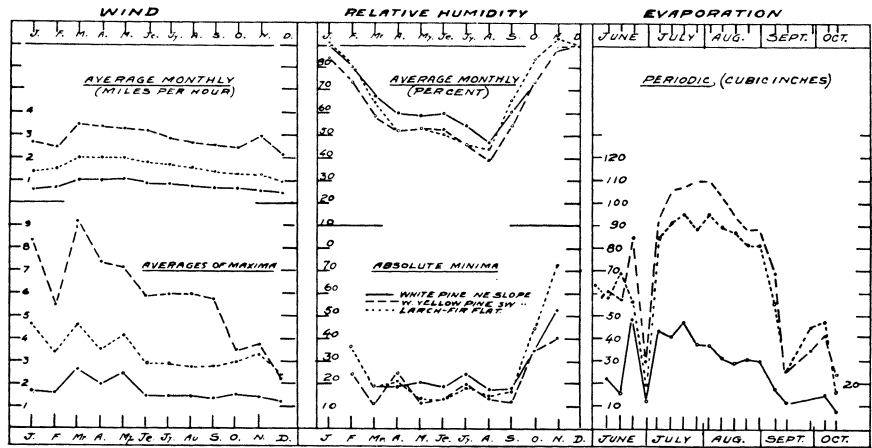


FIGURE 6.

TABLE 5. RELATIVE HUMIDITY IN PERCENT (READINGS TAKEN AT 6 P.M.)

	AVERAGE MONTHLY			LOWEST MONTHLY			ABSOLUTE MINIMUM		
	Control Flat	SW Slope	NE Slope	Control Flat	SW Slope	NE Slope	Control Flat	SW Slope	NE Slope
REST PERIOD									
October.....	84.5	74.1	73.5	75.3	65.2	65.1	45.0	35.0	35.0
November.....	93.5	88.8	89.7	91.2	84.9	87.6	73.0	41.0	53.0
December.....	90.8	89.5	90.0	80.9	87.7	84.2	76.0	43.0	43.0
January.....	91.7	85.0	90.0	83.8	69.4	79.8	72.0	23.0	46.0
February.....	82.0	74.0	80.8	79.0	64.0	74.3	40.0	25.0	37.0
March.....	64.9	59.3	67.6	56.5	49.7	61.3	19.0	11.0	19.0
April.....	51.9	52.5	60.0	46.4	46.0	47.6	21.0	25.0	19.0
Average.....	79.9	74.7	78.8	73.3	66.7	71.4	.....	.....	.....
Lowest.....	.....	.....	.....	.....	.....	.....	19.0	11.0	19.0
GROWTH PERIOD									
May.....	52.8	53.6	59.2	44.7	43.6	50.1	14.0	12.0	21.0
June.....	50.8	52.9	60.0	42.8	49.7	57.5	13.0	13.0	19.0
July.....	46.5	46.0	54.9	36.0	32.3	43.1	19.0	20.0	25.0
August.....	44.1	38.9	47.1	26.2	23.6	33.0	15.0	14.0	18.0
September.....	66.2	54.6	60.4	60.8	45.6	56.0	17.0	12.0	18.0
Average.....	52.1	49.2	56.3	42.1	39.0	47.9	15.6	14.2	20.2
Year.....	68.3	64.1	69.4	57.8	55.1	61.8	.....	.....	.....
Lowest.....	.....	.....	.....	.....	.....	.....	15.0	12.0	18.0

registered on the southwest slope and the flat are very small. August marks the climax of the increasing dryness of the air with the progress of the summer, with an average of 44.1 percent on the flat, 38.9 percent on the southwest slope, and 47.1 percent on the northeast slope. But the lowest actual monthly humidity, that is, the month of lowest average in any of the 5 years, indicates the relative severity more accurately than either the 5-year averages or the absolute minima. These values are: larch-fir flat, 26.2 percent; western yellow pine, southwest slope, 23.6 percent; and western white pine, northeast slope, 33.0 percent.

The air on the flat at Station 1 is seemingly more humid in late fall and winter than on the other sites. But this is not true; the discrepancy is due to the later time of reading at Station 1, at a time of the day when the relative humidity increases rapidly with a lowering of the temperature after sunset.

It is, of course, well recognized that through increase in temperature during the day the relative humidity is lowered. This has its influence in creating extremely dry surface and upper soil conditions, especially on western yellow pine and pure Douglas fir sites, a factor or condition which tends to eliminate new seedlings of mesic species.

TABLE 6. WIND MOVEMENT IN MILES PER HOUR

	AVERAGE			AVERAGE MAXIMUM			ABSOLUTE MAXIMUM		
	Control Flat	SW Slope	NE Slope	Control Flat	SW Slope	NE Slope	Control Flat	SW Slope	NE Slope
REST PERIOD									
October.....	1.3	2.5	0.7	3.0	3.5	1.6	4.0	9.0	2.5
November.....	1.3	3.0	0.6	3.4	3.8	1.5	4.2	9.2	1.9
December.....	1.0	2.2	0.5	2.5	2.3	1.3	4.4	10.6	1.7
January.....	1.4	2.7	0.6	4.7	8.4	1.7	11.2	14.0	2.5
February.....	1.5	2.5	0.7	3.4	5.5	1.6	5.4	8.4	1.7
March.....	2.0	3.5	1.0	4.7	9.2	2.7	7.0	11.9	4.3
April.....	2.0	3.4	1.0	3.5	7.4	2.0	3.7	9.2	2.7
Average.....	1.5	2.8	0.7	3.6	6.5	1.8	5.7	10.2	2.5
GROWTH PERIOD									
May.....	2.0	3.3	1.1	4.2	7.2	2.5	5.7	8.7	2.9
June.....	1.8	3.2	0.9	2.9	5.9	1.5	3.3	6.8	2.1
July.....	1.7	2.9	0.9	2.9	6.0	1.5	3.7	7.6	2.0
August.....	1.6	2.7	0.8	2.8	6.0	1.5	3.6	7.6	1.9
Sept.....	1.4	2.6	0.7	2.8	5.8	1.4	4.0	8.6	2.0
Average.....	1.7	2.9	0.9	3.1	6.2	1.7	4.0	3.7	2.2
Year.....	...	...	...	...	...	...	...	...	...

WIND MOVEMENT

Wind velocity values are given in Table 6 and Fig. 6. As would be expected, the greatest air movement takes place on the southwest slope, where the average per hour both winter and summer is 2.9 miles and the average maximum for any one day in winter is 6.5 miles and in summer 6.2 miles. These average maxima are about twice the movement on the flat and four times

that on the northeast slope. The greatest wind velocities for the control station occur from 2 to 4 p.m., attaining an average movement of 3.2 to 3.9 miles per hour at 2 p.m. and lowering to about one-half mile per hour at midnight or dawn. These records for northern Idaho are very low compared with the other weather stations; in the Northern Rocky Mountains region for the summer months Spokane shows 5.3; Kalispell 4.4; Helena 7.8; and Yellowstone Park 6.9 miles per hour. The sunshine, wind, and moisture deficits fluctuate in close harmony, especially during the summer months; and because each atmospheric factor reaches its peak on westerly slopes in middle afternoon of each day, the high points of several climatic factors coincide and produce critical extremes. The influence of this situation is more keenly felt on the south and west aspects than elsewhere, particularly in July and August. It is here that seedlings of all species perish in great numbers.

TABLE 7. TOTAL EVAPORATION FROM A FREE WATER SURFACE

			Station 1	Station 2	Station 3
			Total Evaporation and Rainfall in Inches, by 15- and 30-Day Periods for 1916		
June	3-30	Evaporation..	3.19	3.94	1.71
		Rain.....	3.19	3.11	3.13
July	1-31	Evaporation..	4.03	4.48	1.78
		Rain.....	1.66	1.49	1.83
August	1-31	Evaporation..	3.52	3.76	0.84
		Rain.....	1.22	1.12	1.27
September	1-30	Evaporation..	1.86	2.25	1.39
		Rain.....	1.86	1.80	1.86
			Evaporation from Livingston Porous Cup Atmometer in cubic centimeters per day for 1917		
July	1-15.....		30.0	....	....
July	16-31.....		29.3	....	....
August	1-15.....		26.6	30.0	23.4
August	16-31.....		27.6	30.0	26.3
September	1-15.....		12.0	13.1	10.7
September	16-31.....		16.1	21.2	14.1

EVAPORATION

Evaporation for the month of July, 1916 (Table 7 and Fig. 6), was 4.03 inches for the flat; 4.48 for the southwest slope and only 1.78 for the northeast aspect. Rainfall-evaporation ratios were 2.4 for the flat, 3.0 on the southwest slope, and about 1.0 on the northeast slope. In September, however, the ratios are 1.0 at Station 1; close to 1.3 at Station 2 and 0.8 at Station 3.

EDAPHIC FACTORS

SOIL TYPES

The soil tests made in 1932 were correlated with the soil types distinguished and mapped in 1925 by M. H. Lapman and F. O. Young, of the

Bureau of Chemistry and Soils, United States Department of Agriculture; and the following is quoted from their manuscript notes of 1925 in the Experiment Station files: The names and classifications are not to be considered final. (See Fig. 2.) (Note: arabics are used for the numbers as given by the above authors; numbers are given according to stations and other locations in this study. See Table 9.)

Along the Priest River, Benton Creek, East River and its south fork are low, poorly drained alluvial bottoms, comparatively narrow and of small extent. A little higher are terraces or flats of stream-laid or lake-laid origin. These are somewhat eroded and rolling in places, but are for the most part flat.

The upper boundaries marking the edge of the old lake occur just above 2400 feet elevation in most places. Arms of the lake extension reach up along the various creeks which drain the area. . . . The deposit is many feet in thickness; . . . the soil has a smooth to lightly rolling surface. The drainage is generally good, as is the moisture-holding capacity.

The surface soils are remarkably similar in physical characters. . . .

It seems probable that the majority of the soils are somewhat modified by an admixture of loess or fine-floury, wind-borne material. The majority of the soils are remarkably free from horizontal development due to weathering; the subsoil being generally friable and free from marked compaction except in types 14 and 54.

The soil at Station 1, Benton Flat (No. 6), is Springdale sandy loam supporting western larch and some Douglas fir on the edges of the flat. On this flat the sand and gravel are very deep and well sorted, leading to the supposition that lake water, possibly of glacial origin, was instrumental in its formation. Some pits were dug to depths of 7 and 8 feet without striking clay or bedrock.

At Stations 2 and 3, the soil (No. 9 on the map) is Huckleberry fine sandy loam supporting a mixed stand of western yellow pine and Douglas fir on the southwest aspect and mainly white pine on the northeast. This is one of the most important, and by far the most extensive, soil type in the area.

It is a residual soil from schists and quartzites which occur in alternating layers overlying the granite which forms the backbone of the range to the east. The surface soil consists of 12 to 18 inches of light reddish brown fine sandy loam . . . and usually contains a large percentage of gravel or rock. This soil mantle is of a good depth but small patches of rock outcrop are of frequent but irregular occurrence. The steeper phases are generally more shallow and stony. This is particularly true of the steeper phases at 2a.

At Station 3a the soil (No. 31) is also a steep, stony phase of No. 9, derived from the same parent material. At Station 2a there is also a mantle of Huckleberry fine sandy loam covering a steeper, more stony surface without humus or litter except under the scattered clumps of evergreen shrubs.

The soil (No. 54) at Station 4 is gray clay . . . consisting of a light gray, rather compact heavy clay loam or clay over a light gray compact clay subsoil. It is the same lake-laid material which forms the subsoil of the Mission

fine sandy loam. The surface soil when exposed is apt to pack and bake into a rather impervious condition, and this may render it difficult for young trees to get a start. Once established, however, timber thrives, and a protective cover of duff prevents baking and helps to absorb moisture which might otherwise run off. The surface is generally somewhat rolling or sloping as the material is exposed along the terrace slopes. The surface drainage is somewhat excessive, though the sub-drainage is slow. In moisture holding this soil rates very high.

It supports the more mesic of the forest associations; western red cedar, hemlock, and white fir, as well as western white pine.

Soil type 14 (4a) is a fine sandy loam, which is compact, friable, light brown or yellowish brown fine sandy loam and distinctly micaceous. The subsoil of gray clay with rusty particles occurs at a depth from a few inches to two feet. This clay subsoil is apparently a part of an old lake deposit, the remnants of which are found in a number of places in the vicinity.

SOIL PROPERTIES

The mechanical analyses of the soils made at Priest River in 1915 are given in Table 8, and all essentials of the mechanical, physical, and chemical study made at a later date have been entered in Tables 9 and 10.

The mechanical analysis data given in Table 8 reveal the stony nature of the southwest and northeast sites, the first of which contains mostly western yellow pine, and the second pure Douglas fir. There is present in the soil at these two locations very much less of the finer material than is found where white pine thrives. In this series of tests 56 per cent of the total weight of the sample from the northeast white pine site passed the one-half millimeter sieve and 67.6 percent from the white pine-cedar hemlock flat at Station 4.

By the mechanical analysis given in Table 9 it is well demonstrated that the soil which supports western white pine, with cedar and hemlock, contains a greater clay fraction; and that where Douglas fir and western yellow pine grow, the soils have a correspondingly higher sand fraction. The amount of silt increases under the hydrophytic species and is present in smaller degrees under larch, Douglas fir, and western yellow pine.

TABLE 8. MECHANICAL ANALYSIS OF SOILS BY SIFTING (TESTS MADE AT PRIEST RIVER STATION IN 1915)

Location	Soil type	PERCENT PASSING MESH BY WEIGHT						Total used
		5 mm.	4 mm.	3 mm.	2 mm.	1 mm.	½ mm.	
Station 1; Flat.....	6	9.2	5.1	5.9	12.9	27.6	39.3	272
Station 2; SW Slope.....	9	24.5	5.2	4.2	15.0	5.6	45.4	261
Station 3; NE Slope.....	9	26.5	3.4	3.0	3.4	4.3	59.0	233
Station 3a; NW Slope.....	31	38.5	6.8	4.4	9.2	9.7	30.7	293
Station 4; Flat.....	54	1.9	1.9	6.2	10.5	11.9	67.6	210

TABLE 9. MECHANICAL AND CHEMICAL PROPERTIES OF THE SOILS (BASED ON A STUDY OF SOILS TESTED IN 1932)

Station No.	Map No.	Location	Soil Type	Forest Type	Sand	Silt	Clay	Carbon	Organic Matter	Total N.	Phosphorus	pH
1.....	6	Benton flat..	Sandy loam.....	Larch-fir.....	Per-cent 62.43	Per-cent 19.54	Per-cent 18.03	Per-cent 1.405	Per-cent 3.422	Per-cent 0.1114	Per-cent 0.1422	6.72
2.....	9	SW slope....	Fine sandy loam...	W. yellow pine.....	50.99	33.61	15.40	2.142	3.693	0.0084	0.1070	6.22
2a.....	9	SW slope....	Fine sandy loam (steep phase)....	W. yellow pine.....	36.18	47.93	15.89	0.577	0.994	0.0825	0.0739	6.89
3.....	9	NE slope....	Fine sandy loam....	W. white pine.....	30.98	32.78	26.50	1.430	2.465	0.1061	0.1455	6.98
3a.....	31	NW slope....	Sandy loam (stony phase)....	W. white pine.....	39.14	36.18	24.68	1.261	2.174	0.0803	0.1016	7.02
4.....	54	Moist flat....	Gray clay.....	Douglas fir.....	17.39	35.01	47.60	1.049	1.809	0.0889	0.2069	6.75
4a.....	14	Low SW slope	Fine sandy loam...	W. white pine, cedar, hemlock.....	32.03	39.09	28.88	1.306	2.251	0.0754	0.1472	6.37
4b.....	18	River bench..	Clay loam.....	Larch-white pine....	14.39	53.41	39.02	2.315	3.990	0.1259	0.2872	6.52
5.....	—	River flat....	Clay loam.....	White pine, cedar, hemlock.....	12.53	54.10	33.37	1.745	3.008	0.0972	0.1598	6.02
6.....	—	Rolling land..	Sandy loam.....	Old W. white pine....	37.13	29.35	33.52	1.259	2.176	0.0918	0.1254	6.68
7.....	14	Podzol.....	Over-fine loam....	W. white pine.....	19.73	54.16	34.43	3.030	5.220	0.1550	0.0825	6.34

At Station 2, on the southwest aspect, the physical soil characters are intermediate, and here we observe that occasional Douglas firs grow in mixture with the yellow pine. At Station 2a (steep phase SW slope) the clay

fraction is very low and all of the other physical characters are strikingly similar to those found under the old yellow pine forest represented in Table 9 by number 6.

The soil of the Benton Creek flat (No. 54) surrounding Station 4, and that of the virgin forest of western white pine in Station 5 are very similar to the other mesophytic sites measured, both of them showing heavier portions of silt and clay. A comparison of 2, 2a and 3, which are derived from the same parent rock, but now resting on different aspects, reveals no appreciable variation in the sand and the silt portions, but a much greater clay fraction in the mantle under the white pine forest on the northeast slope. Western yellow pine, Douglas fir, and larch appear on lighter soils.

CHEMICAL PROPERTIES OF THE SOILS

Data on the chemical relations of the soils are given in Table 9. In general, wherever one chemical element is low, as on the more xeric sites, the

TABLE 10. WATER RELATIONS OF THE SOILS

Soil Number and Station Aspect	Soil Type	Forest Type	WATER RELATIONS					Wilting Coefficient
			Saturation	Holding	Capillary	Gravitational	Hygroscopic	
			Percent	Percent	Percent	Percent	Percent	Percent
1 Flat.....	Springdale sandy loam...	Larch-fir.....	50.4	45.05	40.2	10.3	4.85	7.5
2 SW.....	Huckleberry fine sandy loam...	Western yellow pine.....	70.1	62.02	58.4	11.6	3.62	6.9
2a SW.....	Sandy loam (steep).....	Western yellow pine.....	50.7	41.48	38.6	12.2	2.88	6.3
3 NE.....	Huckleberry fine sandy loam...	Western white pine.....	78.7	69.13	62.7	15.9	6.43	10.2
3a NW.....	Sandy loam (stony).....	Douglas fir.....	65.5	59.65	63.8	11.8	5.85	10.2
4 Flat.....	Gray clay.....	Western white pine, cedar, hemlock..	74.3	59.85	53.8	20.2	6.05	11.3
4a SW.....	Mission fine sandy loam...	Larch-white pine..	79.1	73.81	67.9	14.6	5.91	12.1
4b River Bench..	Loam.....	White pine, cedar, hemlock..	104.8	96.27	89.8	14.7	6.47	6.7
5 River Flat...	Loam.....	Old white pine.....	89.7	81.26	74.5	15.0	6.76	9.4
6 Rolling.....	Sandy loam.....	Old yellow pine...	39.7	35.06	29.4	10.3	5.66	5.1
7 Podzol.....	Mission fine loam.....	Western white pine.....	101.6	56.07	48.4	16.2	7.67	—

other elements are also more limited. Soils of lighter texture and of lower water holding capacity under the xerophytic species carry from one-third to one-half of the nitrogen, phosphorus, and carbon found in the heavier soils. The steep slope at Station 2a and the rather steep northeast site at 2 show a strong contrast: the former with western yellow pine carries only one-third to one-half of the chemical elements present on the white pine slope.

Most soils are mildly acid and show a slight tendency toward greater acidity in the older stands, but not of a nature to prevent humus decomposition or create raw humus. The old-growth western white pine forest soil contains considerably more carbon, nitrogen, and phosphorus than the old-growth western yellow pine.

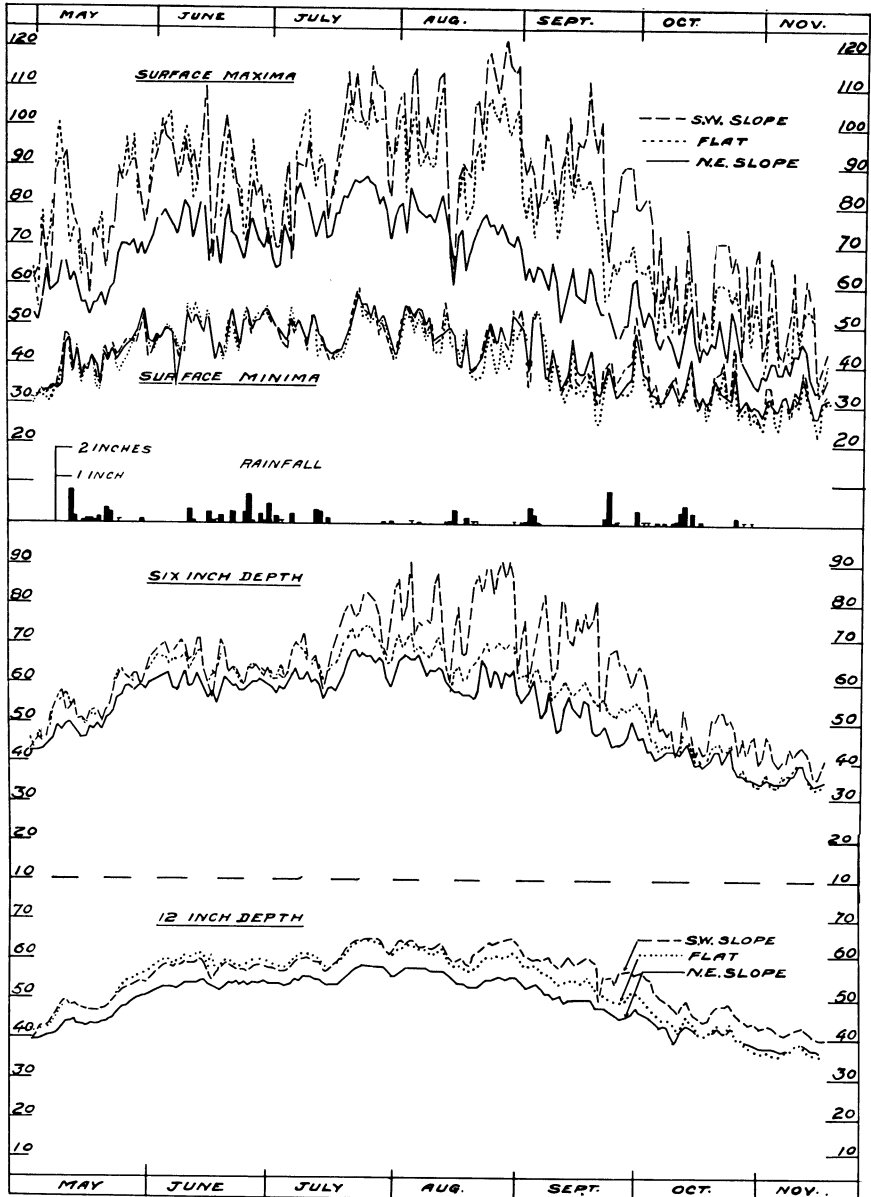


FIG. 7. Daily soil temperatures in degrees Fahrenheit for the period May through November, 1913.

For some years subsequent to the destruction of a forest by fire, the soil may become alkaline especially in the upper layers. This alkalinity stimulates seedling development because of the more readily available nutrients and the absence of competition. Reaction to this advantage appears more vigorously in western yellow pine, western white pine and larch than in the remaining species.

WATER RELATIONS OF THE SOILS

The soil structure influences its water relations to a marked degree. The characteristic water relations of the various soils are given in Table 10. The capillary water, the water-holding capacity, the amount of water required to saturate, the gravitational and hygroscopic moisture, and the wilting coefficients all vary in the same direction, showing greater magnitude for white pine, cedar and hemlock sites (Nos. 3 and 4 and sample 4b and 5), and lowest for virgin western yellow pine. These soil properties are distinctly intermediate for Douglas fir and western larch. The knowledge gained of the different soils by the laboratory tests is corroborated by the field moisture studies given in the section on soil moisture.

SOIL TEMPERATURE

The monthly soil temperature correlations graphs for the several stations are given in Fig. 4b. Records for the soil temperatures obtained in 1913 have been presented in Fig. 7a; data for 6, 12, and 24 inch depths in 1913 in Fig. 7b; and the daily comparison graphs for the entire season of 1915 in Fig. 8. A summation of days having specific soil temperatures has also been prepared (Table 11).

The averages of the surface soil maxima show generally higher values on the southwest slope than elsewhere, although the stations on the flat show nearly as high an average maxima, with occasional higher daily readings.

TABLE 11. DAYS HAVING SPECIFIC SOIL TEMPERATURES AT 1 TO 6 INCH DEPTH, 1912 TO 1916

Season	Station	Freezing	Cold	Cool	Warm	Hot
		Below 32°F.	32.1-40	40.1-50	50.1-60	Above 60°F.
Rest period	1 Flat	34.0	111.5	62.5	5.0	0.0
	2 SW	6.0	122.5	64.5	0.0	0.0
	3 NE	6.0	148.5	57.5	5.0	0.0
	4 Flat	....	146.0	62.0	19.0	0.0
Growth period	1 Flat	0.0	0.0	17.0	79.0	57.0
	2 SW	0.0	0.0	11.0	106.0	65.0
	3 NE	0.0	1.0	45.0	110.5	0.5
	4 Flat	0.0	0.0	26.0	77.0	16.5
Entire year	1 Flat	34.0	111.5	79.5	84.0	57.0
	2 SW	6.0	122.5	75.5	106.0	65.0
	3 NE	6.0	149.5	103.0	115.5	0.5
	4 Flat	....	146.0	88.0	96.0	16.5

The highest surface soil temperature on record on the southwest slope reached the capacity of the thermometer at 125° F.; the extreme temperatures on the flat and on the northeast slope are 118° and 90° F., respectively. The lowering of the curve for the northeast slope in the afternoon is also due to the depression of the angle of inclination of the sun at that time.

In Figure 7a an effort has been made to correlate the maxima and minima of temperatures in the upper inch of soil. The most noticeable feature here is the remarkable uniformity in the daily minima and the pronounced divergence in the maxima. The higher the maxima, the greater will be the spread between the protected and the exposed aspects. On one day, August 27, 1913, this difference reached 45° F. At the close of the season, during late September and early October, the maxima at the different sites became more uniform. The temperatures shown in Fig. 7a have a close bearing on the germination and survival in the seeding tests discussed later.

The lower soil depths ordinarily have less heat than the upper levels in summer and fluctuate more slowly, with a definite lag of one day at 12 inches and two days at 24 inches. At times during the summer when a sudden drop in air temperature takes place, there is a complete reversal of the customary order; the surface soil then has a lower temperature than the soil at greater depths.

At the 6-inch depth and the 12-inch depth, and deeper (Figs. 7b and 8) the southwest slope is shown to be the warmest of the four sites, and the northeast slope the coldest. Temperatures for the lower depth are more moderate, with lesser diurnal fluctuations.

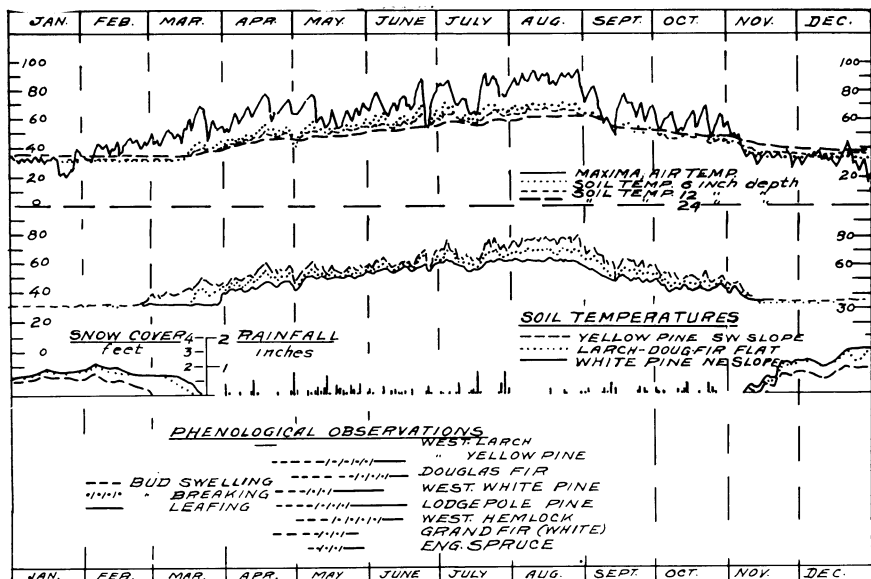


FIG. 8. Relation of air and soil temperature (degrees F.), snow cover, and rainfall.

When discussing soil temperatures it is well to bear in mind that the composition of the soil particles themselves and the water present affect in no small degree the absorption of solar radiation. A large amount of rock, gravel, and sand favor rapid heating, the moister soils responding more slowly. For these reasons the temperature fluctuations of the clay soil on the flat at Station 4 are more like those of the soil on the northeast slope than

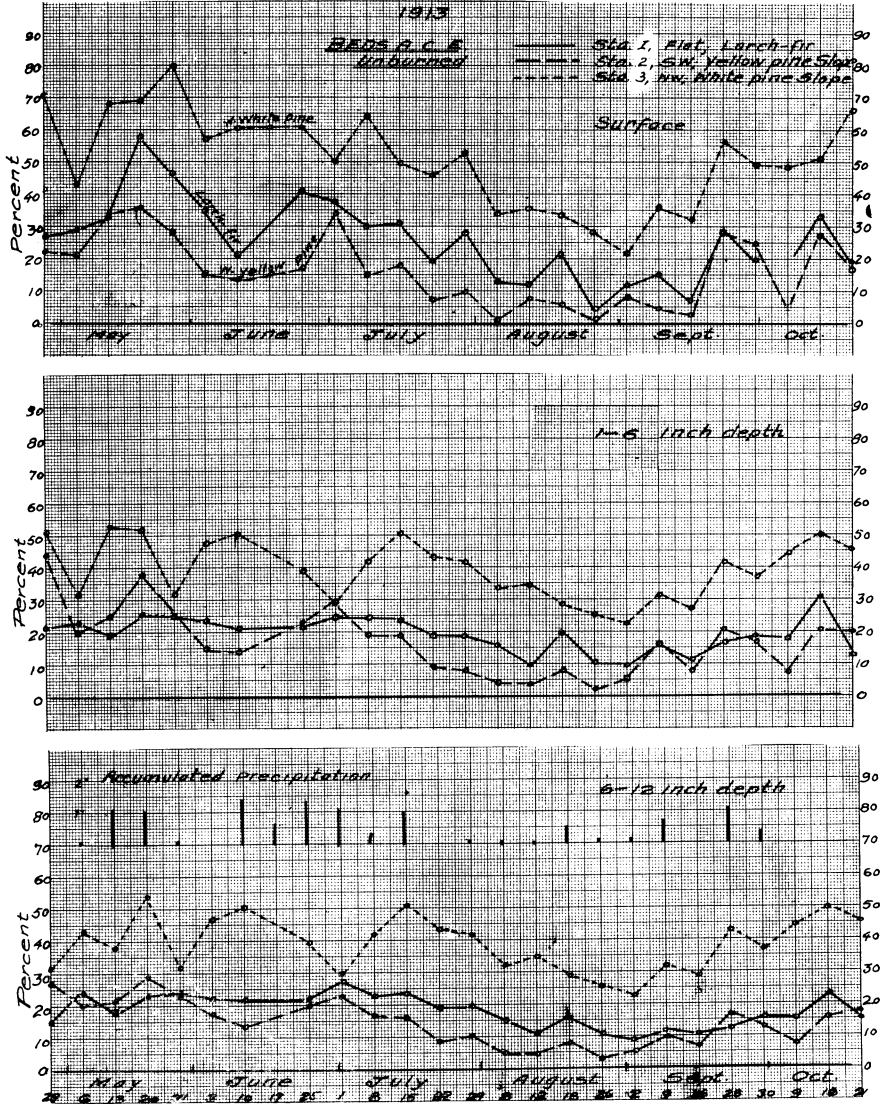


FIG. 9. Moisture content of soils for surface, 6-inch and 12-inch depths at Stations 1, 2, and 3 for the entire growing season of 1914 in unburned ground.

of those on the other sites. The western yellow pine sites show high surface heat and extremes generally, with more even and moderate conditions on western white pine sites.

In Figure 8 we may observe the relations existing between the air temperature and snow cover; the relation of air temperature to the beginning of growth in spring for the different species; and the influence of the daily air temperatures on the heat imparted to the soil at different depths.

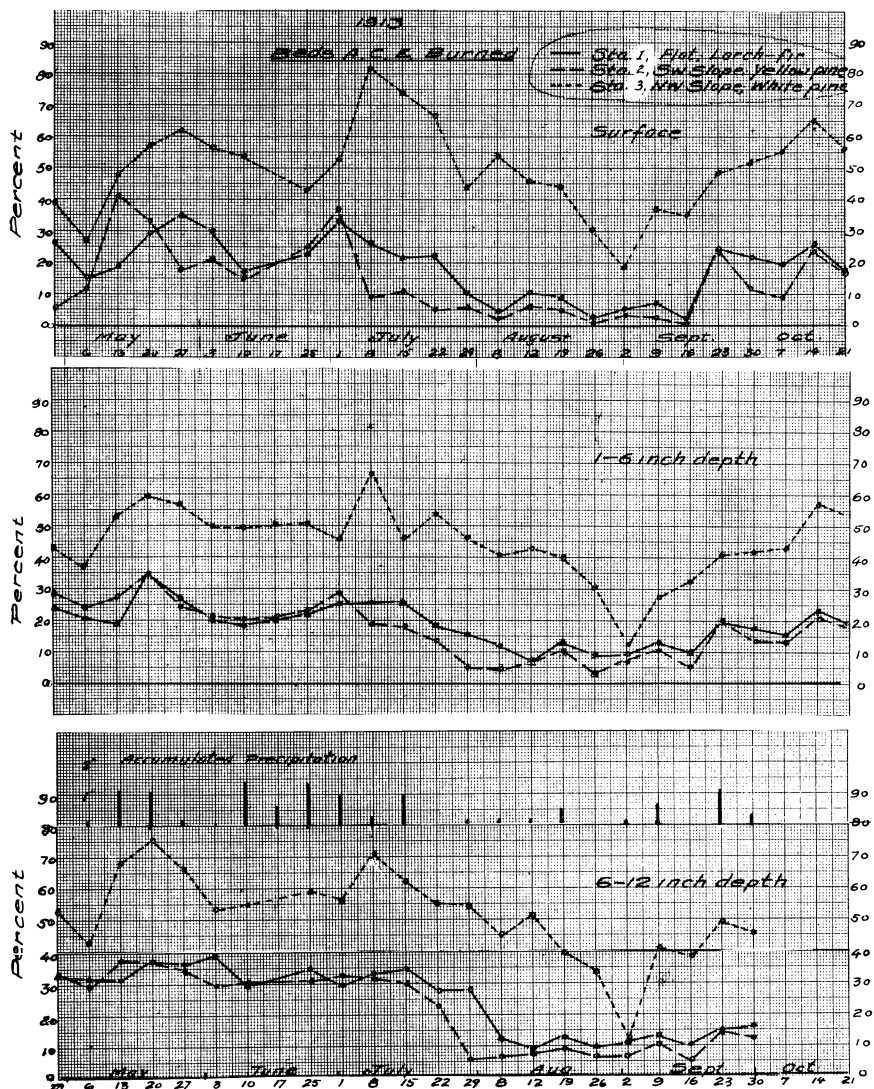


FIG. 10. Field moisture content of soils for surface, 6-inch and 12-inch depths at Stations 1, 2, and 3 for the entire growing season of 1914 in burned ground.

It is observed that no increase in soil temperature is possible before complete snow melting, and that the soil temperature rises almost immediately after the snow mantle is removed. Underneath a snow cover the soil at a depth of 6 inches remains at about 32° F. throughout the winter, but is from 2 to 3 degrees warmer at a depth of 24 inches.

The time of beginning of growth and its relation to air temperature is also given in Fig. 8. This shows the comparatively early start of larch; late beginning of spruce and the intermediate and simultaneous beginning of western white pine, lodgepole pine; with grand fir, Douglas fir, and hemlock last. These records refer to the forest surrounding the Experiment Station buildings and more particularly at altitudes near 2,300 feet. They are therefore related to temperature data obtained on the flat.

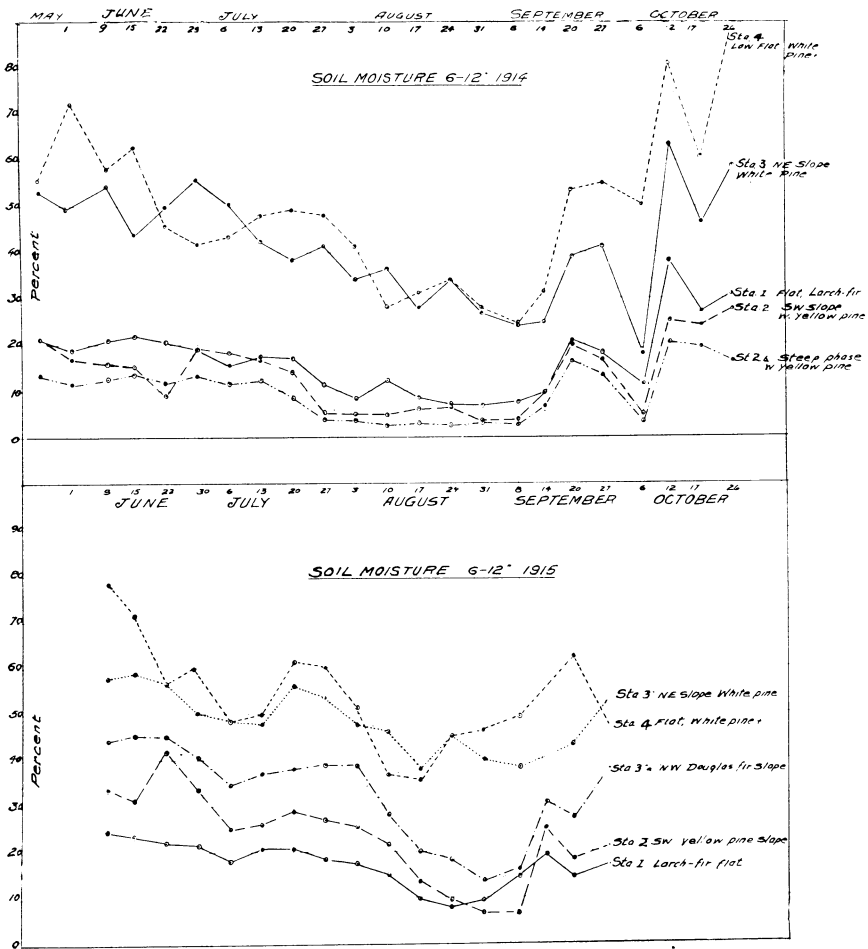


FIG. 11. Field moisture content of soils at Stations 1, 2, 3, and 4 at 6- to 12-inch depths for the entire growing seasons of 1914 and 1915.

FIELD SOIL MOISTURE DETERMINATIONS

Soil moisture data are available largely through field determinations made from 1913 to 1915, inclusive. These are expressed in percentage of dry weight of soil and are given in graphic form in Figs. 9, 10, and 11, the first two for the 1913 season and the last for 1914 and 1915. In Figure 10 are given the three-station relations for surface, 1 to 6 inch and 6 to 12 inch depths in the unburned seeding plots. Some variations occur from year to year, but in the main the relations between the stations continue rather constant. The soil moisture on the northeast aspect and on the low flat, with

TABLE 12. SOIL MOISTURE IN PERCENTAGE OF DRY WEIGHT IN SEEDBEDS AT 1 TO 6 INCH DEPTH IN 1913

Surface	FLAT		SW SLOPE		NE SLOPE	
	Average	Minima	Average	Minima	Average	Minima
Vegetation.....	19.7	9.6	16.5	2.1	40.1	21.9
Burned.....	18.4	6.9	16.7	2.8	45.2	11.8

TABLE 13. MEAN AND MINIMA OF SOIL MOISTURE IN PERCENTAGE OF DRY WEIGHT FOR AUGUST, 1914

Depth	STATION 1 FLAT		STATION 2 SW SLOPE		STATION 3 NE SLOPE		STATION 4 FLAT	
	Mean	Minima	Mean	Minima	Mean	Minima	Mean	Minima
Surface.....	7.0	2.1	7.7	0.5	43.6	0.7	19.1	0.4
1-6 inch.....	12.8	5.7	12.6	2.1	43.7	11.8	36.5	10.3
6-12 inch.....	13.4	5.0	13.2	2.6	43.9	11.9	39.3	10.6

TABLE 14. SOIL MOISTURE IN PERCENTAGE OF DRY WEIGHT IN LOCAL AND COMMON SOILS AT 1 TO 6 INCH DEPTHS FOR AUGUST, 1915

Soil type	STATION 1 FLAT		STATION 2 SW SLOPE		STATION 3 NE SLOPE		STATION 3A NW SLOPE		STATION 4 LOW FLAT	
	Ave.	Min.	Ave.	Min.	Ave.	Min.	Ave.	Min.	Ave.	Min.
Local soil.....	10.1	7.3	12.1	4.6	33.7	.....	37.3	14.9	21.8	16.7
Common soil.....	9.2	6.3	8.6	3.4	19.2	19.2	30.5	12.5	15.3	13.8

western white pine and cedar-hemlock association, is always in excess of that on the other slopes. As the summer advances, white pine sites maintain high and safe levels, the steep northwest aspect becomes intermediate and the steep phase western yellow pine at 2a the driest. On the exposed western yellow pine site and on the flat the surface minima become surprisingly low. This brings about critical conditions in seed germination and seedling survival, but with small influence on the well established forest trees.

It was found that the moisture content at 6 to 12 inch depths for 1914, an average dry year, hovered around the minimum for a period of 42 days on the western yellow pine slopes and for a period of 25 days on the flat, but did not go below 20 percent on the white pine northeast aspect.

SEEDING TESTS

The results of the seeding tests are given in Table 15. In Fig. 12 are shown the distribution of seedlings in the quadrats in the presence of vegetation.

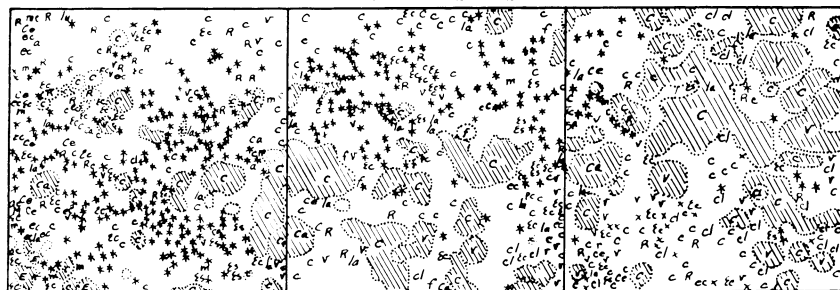
TABLE 15. GERMINATION, SURVIVAL, AND GROWTH OF SEEDLINGS, 1913-1917

Site	LOCATION		GERMINATION PERCENT		Percent survival to 1917	Height in 1917 in inches	LOSSES IN 1913, PERCENT				
	Bed	Surface	1913	Total			Damp- ing off	Ro- dents	Non- estab.	Cut- worm	Un- known
WESTERN WHITE PINE											
Flat....	E	Natural	7.0	10.5	7.2	6.5	66.6	—	—	11.1	22.3*
Flat....	E	Burned	3.2	12.8	90.6	6.9	53.9	—	—	38.5	7.6
SW....	C	Natural	1.2	9.1	0.0	—	50.0	13.6	—	22.6	13.6
SW....	C	Burned	0.7	6.9	0.0	—	72.7	—	—	—	27.3
NE....	A	Natural	11.4	12.8	82.9	4.3	30.3	—	3.0	16.7	50.0
NE....	A	Burned	10.9	13.8	84.6	4.6	56.3	—	6.3	12.5	25.0
DOUGLAS FIR											
Flat....	E	Natural	15.9	17.9	80.0	5.7	52.0	0.0	8.7	0.0	39.3
Flat....	E	Burned	22.6	23.2	65.6	10.2	46.8	0.0	36.1	0.0	17.1
SW....	C	Natural	3.7	7.3	2.7	—**	73.6	0.0	0.0	11.7	14.7
SW....	C	Burned	4.3	7.5	2.7	—	74.4	2.3	0.0	4.6	18.7
NE....	A	Natural	0.5	5.1	25.9	6.0	77.5	0.0	6.5	6.5	9.5
NE....	A	Burned	15.0	15.6	79.5	5.5	40.5	0.0	9.5	0.0	50.0
WESTERN HEMLOCK											
Flat....	E	Natural	1.0	1.0	0.0	—	26.1	0.0	0.0	0.0	73.9
Flat....	E	Burned	4.0	4.0	1.7	—	74.6	0.0	0.0	0.0	21.1
SW....	C	Natural	3.0	3.0	0.0	—	87.8	0.0	0.0	0.0	12.2
SW....	C	Burned	0.03	0.03	0.0	—	100.0	0.0	0.0	0.0	0.0
NE....	A	Natural	3.4	3.4	27.9	6.7	46.0	0.0	0.0	0.0	54.0
NE....	A	Burned	2.9	3.1	32.0	2.2	43.0	0.0	21.5	0.0	35.5
WESTERN YELLOW PINE											
Flat....	E	Natural	17.6	21.6	87.5	8.8	35.6	0.0	10.8	10.8	42.8
Flat....	E	Burned	45.6	49.0	84.5	10.6	50.0	0.0	21.2	0.0	28.8
SW....	C	Natural	18.4	21.9	34.2	7.6	66.6	4.2	4.2	4.2	20.8
SW....	C	Burned	15.3	20.1	77.6	8.5	56.5	0.0	0.0	17.4	26.1
NE....	A	Natural	23.4	23.7	54.8	7.0	78.0	0.0	2.5	0.0	19.5
NE....	A	Burned	41.6	41.7	71.7	9.4	57.6	0.0	11.6	7.1	23.5
WESTERN LARCH											
Flat....	E	Natural	2.5	2.8	17.2	2.6	66.6	0.0	0.0	2.1	31.3
Flat....	E	Burned	7.8	9.2	9.4	4.1	72.9	0.0	11.8	1.2	14.1
SW....	C	Natural	2.4	12.4	0.0	—	87.2	1.1	0.0	1.7	10.0
SW....	C	Burned	1.8	6.4	0.0	—	54.6	20.6	2.4	0.0	22.1
NE....	A	Natural	1.6	1.6	6.6	—	79.2	0.0	3.0	0.0	17.8
NE....	A	Burned	2.2	3.6	7.2	2.4	73.0	0.0	4.3	0.0	22.7
WESTERN RED CEDAR											
Flat....	E	Natural	0.2	0.2	33.2	—	66.7	0.0	0.0	0.0	33.3
Flat....	E	Burned	0.2	0.2	10.0	—	42.8	0.0	0.0	0.0	57.2
SW....	C	Natural	0.1	0.1	0.0	—	50.0	0.0	0.0	0.0	50.0
SW....	C	Burned	0.02	0.02	0.0	—	0.0	0.0	0.0	0.0	—
NE....	A	Natural	0.2	0.2	22.2	2.0	43.0	0.0	0.0	0.0	57.0
NE....	A	Burned	0.4	0.4	29.0	4.2	33.3	0.0	0.0	11.0	55.7

*Percentages of total 1913 losses.

**Losses subsequent to 1915.

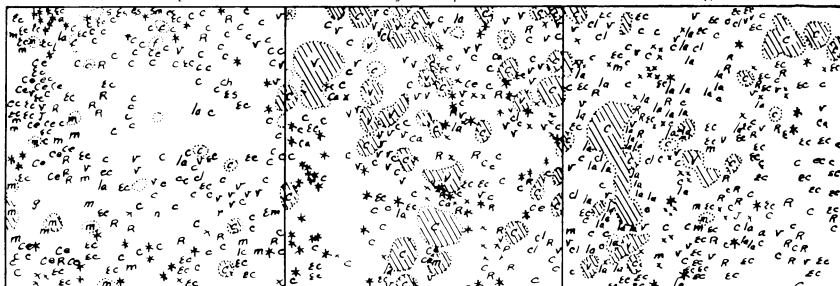
BED A NORTHEAST ASPECT



W. white pine

W. yellow pine

Douglas fir

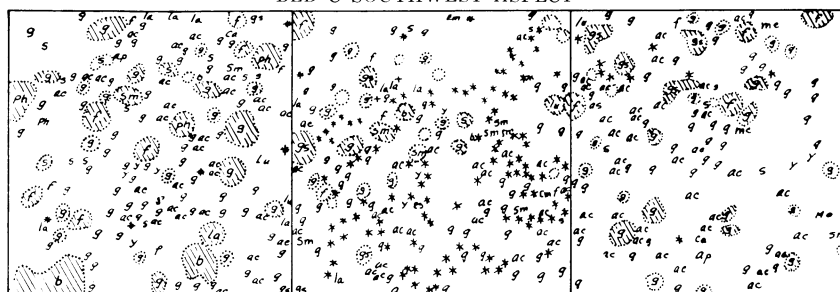


West. larch

West. hemlock

West. red cedar

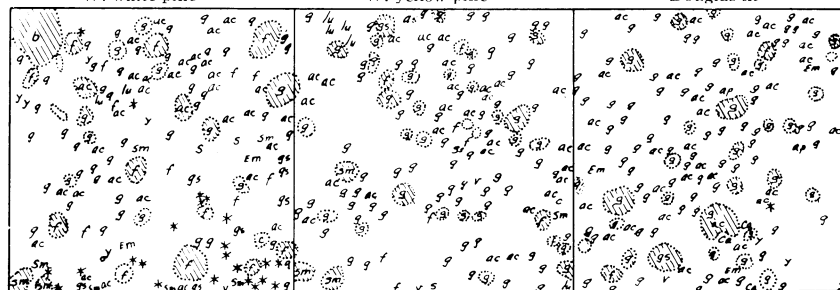
BED C SOUTHWEST ASPECT



W. white pine

W. yellow pine

Douglas fir



West. larch

West. hemlock

West. red cedar

- | | | | |
|--------------------------|----------------------|---------------------|-----------------------|
| * -Coniferous seedlings | V - Viola | Em - Epilobium sp. | Am - Amelanchier aln. |
| /// - Gro. of vegetation | C - Cortis | f - Fragaria | So - Sorbus |
| xyk - Miscellaneous | R - Rubus | Ga - Galium | Me - Mertensia Myr. |
| gs - Grass | Ce - Ceanothus | Sal - Salix | Ac - Achillea Mel. |
| g - Grass, less dense | Ec - Epilobium col. | h - Hawkweed | Co - Collinsia |
| B - Berberis | Es - Epilobium spic. | Li - Linnaea bor. | S - Sedum Doug. |
| | Me - Menyanthes | Sm - Symphoricarpos | Ap - Apocynum |

FIG. 12. Seeding quadrats on flat, southwest, and northeast slopes at Stations 1, 2, and 3.

The quadrats were made within the seedbeds with undisturbed vegetation and with cleared and burned surfaces. In the burned area liverworts, moss, and ground lichens appeared.

The quadrats were made to show the position of the seedlings, which are marked with asterisks, the type of vegetation on the various plots, and its relation to germination and survival. Hatched areas represent solid mats of vegetation, the individual plants being marked with a key letter. The density of the vegetative cover, therefore, may become a factor affecting the restocking, and since this matter leads us into an unexplored field, further discussion of this phase must be omitted.

Referring to Table 15, it is seen that western white pine germinated best on the northeast aspect in bed A; next best on the flat in bed E; and somewhat poorer on the southwest in bed C. There was generally better germination on the vegetation surfaces, especially during the first season. During the second season, however, many additional seedlings appeared, but more on the burned than on the unburned ground.

The fact that considerable seed of western white pine germinated during the second season after sowing, and that this germination was greater on the exposed southwest slope and flat, indicates that some of the seed remained viable and was better preserved under the drier conditions than in moister surroundings. The second-year seedlings were fully as vigorous as those of the first year.

The white pine survived better on the northeast slope and on the burned surface on the flat than elsewhere, with total failure on the southwest. The survival on the flat continued for a few years until competition eliminated most of the trees. At the end of 1917 the northeast aspect showed by far the best results. A slightly better height growth was observed on the flat than on the northeast slope. (See Fig. 13 for height and general development of the seedlings on the two kinds of surfaces.)

For the western yellow pine the results listed in Table 15 show a germination of 21.6 percent on the natural and 40.0 percent on the burned surface on the flat; 20.0 and 20.1 percent in the same order on the southwest slope; and 23.7 and 41.7 percent on the northeast aspect. From these results it is seen that, except for the exposed western yellow pine slope, the germination practically doubled on burned ground. Survival was good on all sites, but better in general on the burned surfaces than on the unburned; and height growth was much superior on the burned plots.

The second year's germination of western yellow pine increased the stand by 3 to 5 percent on the southwest aspect and on the flat, but not on the northeast. Since the 1913 season was very moist generally, the losses by damping-off were severe, especially on the northeast aspect and in the presence of vegetation.

Douglas fir germinated on the whole best on the flat and poorest on the southwest slope, the burned surfaces holding the lead on all three sites. The

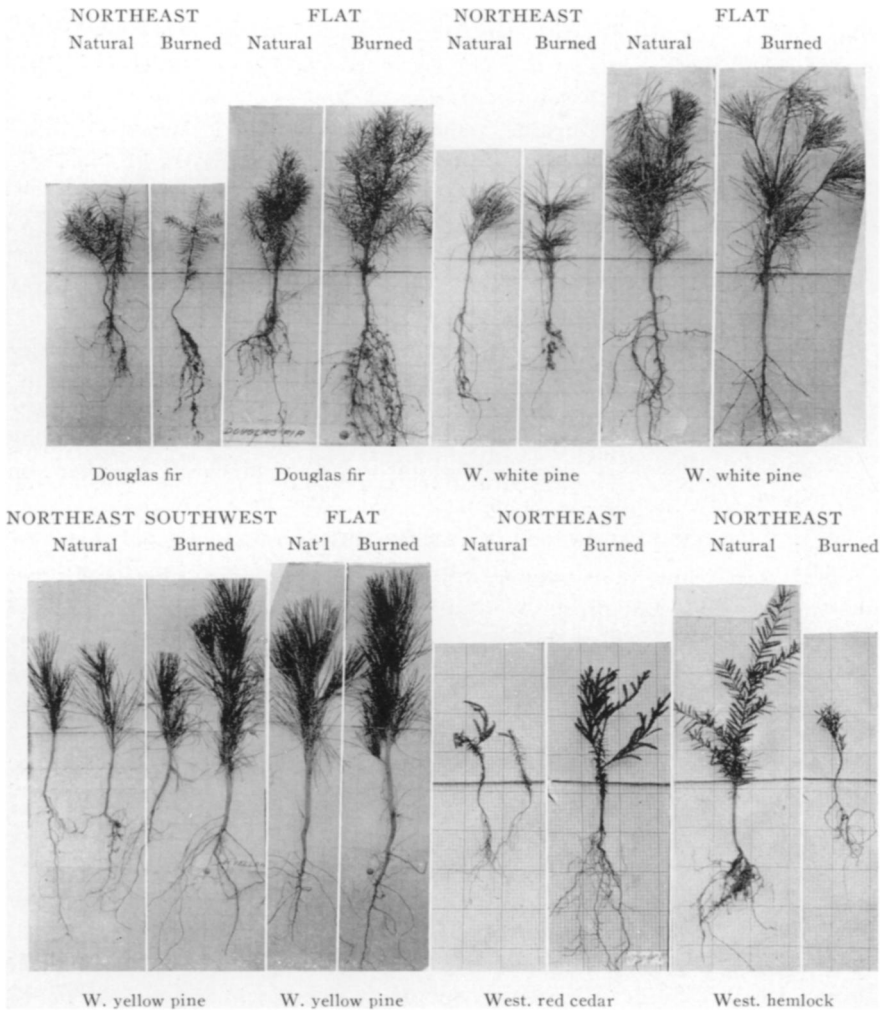


FIG. 13. Development of seedlings on burned and unburned surfaces at Stations 1, 2, 3, or flat, southwest, and northeast aspects.

second season's germination took place in all of the beds and added from 0.6 to 3.5 percent, being strongest in the presence of vegetation. Survival showed nothing on the southwest aspect in 1917, medium on the northeast aspect, and good on the flat; height growth was 10.7 inches on the burned surfaces, and only 5.7 inches in vegetation on the flat. For the northeast slope the height growth gave 6.0 inches in vegetation and 5.5 on burned surface (Table 15 and Fig. 13). Losses by damping-off were uniformly severe on all sites.

Germination of western larch showed best results on the burned surfaces, more particularly on the flat, and took the lead in the presence of vegetation

during the second season, with very good results on the southwest slope. Survival on the northeast and the flat continued good until the end of 1917, but was nil on the exposed southwest slope. None survived in the natural surface on the flat. Growth appeared more rapid on the burned surfaces, and losses from damping-off were severe on all sites during the first season.

The seed of western hemlock germinated very much better on the northeast and poorly on the southwest aspect, where it gave the better results on the unburned plot. In this respect we have a reversal from what took place on the flat, for in this location more seedlings appeared on the burned plot. Final survival can be credited only on the northeast location, where it was appreciably better on the natural than on the burned ground. The seedlings in the presence of vegetation grew to greater heights than those on the burned plot. The hemlock stand was greatly reduced by damping-off fungi, this loss being heavier on burned than on unburned surfaces. In this respect, this species differs from all others used in this experiment.

NATURAL SEEDING AND ESTABLISHMENT OF SEEDLINGS

It is true that conditions may exist where individual herbaceous and other plants would reduce the effect of climatic extremes and protect young trees. This seems to have benefited the larch and western red cedar. However, the keen competition for moisture and light which must be endured by the young trees growing in dense vegetative cover usually more than counteracts any advantages from protection afforded by that cover.

That the type of vegetation varies distinctly according to the site or exposure is sufficiently brought out by the lists of species given in Figure 12. On the northeast slope there occurs a larger proportion of the succulent plants, among which are *Viola*, *Clintonia*, *Mertensia*, and *Rubus*, and relatively few drought resisting varieties, such as *Heuchera*, lupine, *Calamagrostis*, *Apocynum*, and *Sedum*, which occur in greater abundance on the southwest exposure. The vegetation on the flat bears a closer resemblance to that on the northeast aspect and supports a great many additional plants of the genera *Achillea*, *Fragaria*, *Carex*, *Berberis*, and *Pentstemon*.

This subdominant surface cover of miscellaneous species moves in its own successional stages and cycles, which are little understood; and although this investigation did not include a quantitative study of the herbaceous cover, the writer recognizes its value and possibilities as an indicator of site characters and quality.

Within the altitudinal zone occupied by the western white pine, cedar, and hemlock, the western white pine is quick to reseed the terrain following single burns and destruction of the old forest. For this reason northern Idaho possesses many splendid stands of relatively pure western white pine. In a great many locations, such as small natural openings in the canopy, cedar and hemlock seed is naturally present along with the pine, both being more mesic and more tolerant of shade than the white pine; but their much slower

growth results in an understory. As the overstory of pine eventually decays, the cedar and hemlock become dominant.

If the western larch, which has temperature and moisture requirements quite similar to white pine, seeds in together with the pine, its rapid height growth enables it to keep ahead of all other species. Its deeper root system gives it an added advantage on sandy benches. It therefore remains in the forest for several hundred years until the climax species succeed the white pine.

Successful establishment and growth of western yellow pine seedlings requires a mean seasonal soil temperature between 60 and 70° F., and from 50 to 100 percent of light in summer. It will tolerate lower soil moisture than any of the other species tried.

Although individual trees of western yellow pine will be found within the young stand on white pine sites, their form and development is much inferior, and their growth slow as a result of competition with the white pine for moisture and light. They are eventually overtopped and suppressed, disappearing from the stand at a relatively early age.

Natural regeneration of Douglas fir succeeds well on both natural and slopes and very cold flats; and it appears that the slight protection offered bare surfaces on north slopes and flats, but is uncertain on the very warm by shrubbery from the drying influence of wind and sun in midsummer and by the accumulation of leaf litter from shrubbery, which improves the moisture capacity of the soil, are here very beneficial to the establishment of Douglas fir. This intermediate species will germinate and become established in western yellow pine stands only with this added protection, and in white pine and cedar stands, if competition is greatly reduced.

For successful establishment of western larch there must be assured sufficient soil moisture in the upper layers of soil 1 to 6 inches and 6 to 12 inches throughout the entire first growing season. This means at least 20 percent of moisture in the soil above the 10-inch level. Fully 75 percent of sunlight is also needed, and unobstructed sunlight is not harmful.

Larch and western yellow pine seldom compete on the same terrain in northern Idaho. They are both quite intolerant of shade, but the larch grows under conditions of lower temperature and higher soil moisture than western yellow pine, and it belongs to a higher zone. If they germinate side by side, the lack of soil moisture becomes the determining factor in favor of the pine; and if soil moisture is sufficient, the larch speedily outgrows the yellow pine.

Competition between the larch and the Douglas fir is chiefly for soil moisture in that these two species grow equally well under identical atmospheric conditions. The larch seedlings cannot survive where the soil moisture becomes low during the middle or latter part of the summer. This leaves the Douglas fir in possession of the steeper gradients similar to the northwest aspect where Station 3a was situated. The larch holds sway on benches and

lower northerly slopes; here it finds favorable conditions for rapid development, often becoming dominant.

Establishment of western hemlock requires soil moisture not below 20 percent and at least 20 percent of full sunlight. These conditions are met on better soil in the breaks in the virgin timber on flats and northerly slopes. The seedlings are rapidly eliminated from bare or exposed surfaces because of a dry soil and lack of protection from heat or too rapid transpiration. Hemlock seedlings have shallow roots. They thrive in moist, sheltered places and on soils with much organic material, especially in decaying wood. They frequently present considerable competition to seedlings of western white pine.

Cedar requires constant soil moisture not below 12 percent in August, such as is found on the north aspects and loamy flats. It will not withstand full sunlight. The failure of western red cedar and western hemlock on the southwest slope is ascribed chiefly to the more exacting conditions arising from the greater wind movement, lower humidity, warmer soil, and the less stable soil-moisture content. Requirements of hemlock and western red cedar are nearly identical; but unlike hemlock, cedar made noticeably better growth on the burned and denuded surface, and appears less selective than hemlock for organic material and decaying wood.

PLANTING TESTS

Results obtained in the planting experiments are given in order for series A, B, C, and D. These tests have been described in the section on methods. Data on survival and growth are included in Tables 16 and 17, and the curves for survival and growth of series A to C, in Figures 14 and 15.

In series A (Figures 14*A* and 14*B*) the western yellow pine proved uniformly better in survival and growth on the flat than on the southwest slope. The height growth was 57 inches at the end of 1921 on the flat and only 15 inches on the slope. It is true that there has been more grass and shrub competition on the slope than on the flat, but even in the absence of competition the trees on the exposed slope measured at the end of 1921 only one-half the height of similar trees growing on the flat. On both sites the transplant stock showed superiority over the seedlings.

In series B (Fig. 14*C*) western yellow pine substantiated in a very clear manner the results obtained in the previous test in showing 56 percent survival and 29.5 inches on the flat compared with 44.0 percent survival and only 15.8 inches in height on the southwest aspect. A proportionately greater mortality occurred among the smaller classes on the southwest aspect than on the flat. This was in all probability caused by the lower moisture content in the soil in the upper layers on the slope; greater air movement, and evaporation.

Since the flat is underlaid by a porous material to considerable depth and the southwest slope rests on solid rock, the plants on the two sites in series A and B were subjected to somewhat unequal soil-moisture condition.

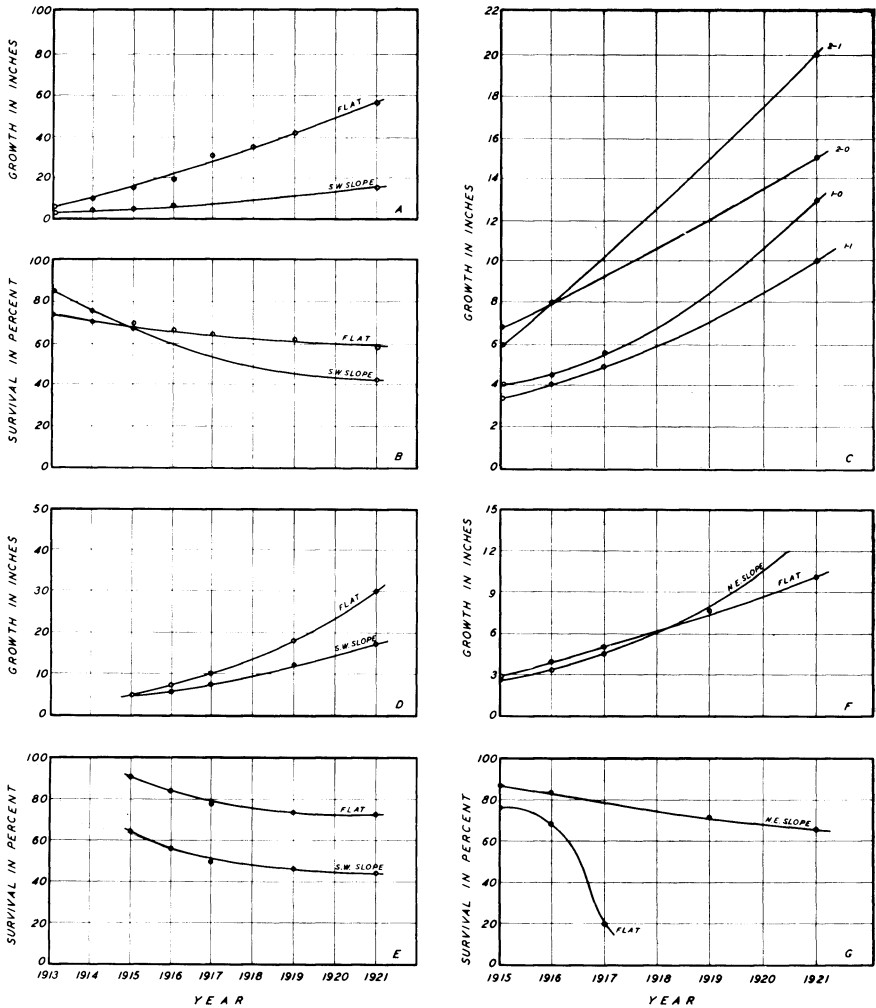


FIG. 14. Survival and growth of planted trees on flat, southwest, and northeast aspects. *A*. Growth of western yellow pine, Series A, on flat and southwest aspect. *B*. Survival of western yellow pine, Series A, on flat and southwest aspect. *C*. Growth of western yellow pine, Series A, on southwest aspect. *D*. Growth of western yellow pine, Series B, on flat and southwest aspect. *E*. Survival of western yellow pine, Series B, on flat and southwest aspect. *F*. Growth of western white pine, Series C, on flat and northeast aspect. *G*. Survival of western white pine, Series C, on flat and northeast aspect.

Series C contained western white pine only and was installed for comparisons on the flat and on the northeast slope. Both in survival and growth this series (Fig. 14*D*) points unmistakably to the northeast aspect as the more suitable site for western white pine, with survival of 78 percent for 1-2 planting stock and 66 percent for 2-0. The flat proved to be a very

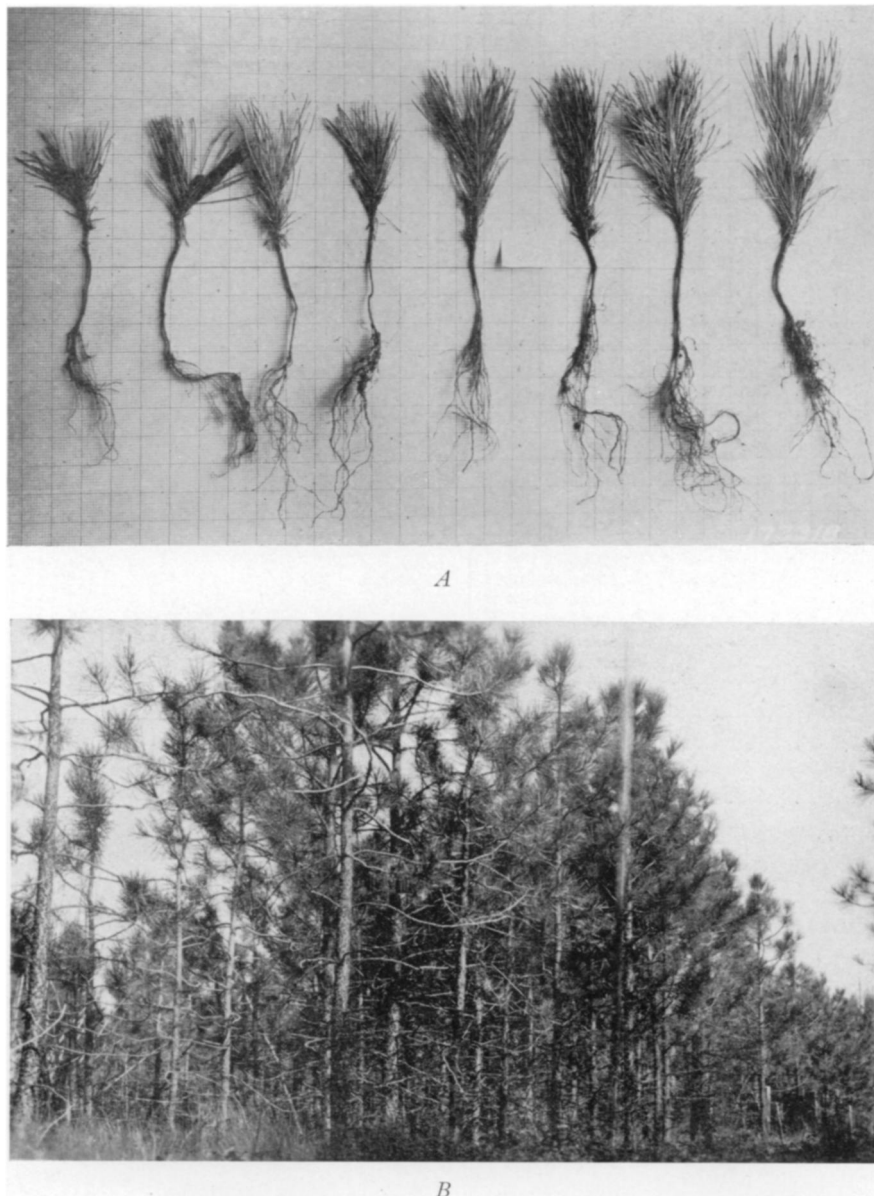


FIG. 15. *A.* Representative stock of western yellow pine planted spring 1914 on the flat and southwest slope. *B.* The same stock as photographed in 1932.

unfavorable environment for western white pine, very few of which remained until 1921. The 1-2 transplants survived and grew better than the 2-0 stock.

On the steep southerly sites in series D (Table 16) 1-2 transplants of western yellow pine showed higher survival than 3-0 stock. The survival of

TABLE 16. SERIES D; PLANTED STOCK OF 3-0 AND 1-2 WESTERN YELLOW PINE ON STEEP PHASE SOUTHERLY ASPECTS

Location	Station	Class	SURVIVAL IN PERCENT		HEIGHT IN INCHES	
			1915	1921	1915	1921
SW Slope.....	2a	3-0	35	22	9.1	21
S Slope.....	2b	3-0	45	24	10.0	23
SE Slope.....	2c	3-0	26	12	11.0	24
SW Slope.....	2a	1-2	61	27	6.7	18
S Slope.....	2b	1-2	65	26	7.7	16
SE Slope.....	2c	1-2	49	14	8.6	21

TABLE 17. GROWTH OF THE DOMINANT TREES IN THE PLANTATIONS TO THE END OF 1932

Series	Location	Species	Average height in inches	Number of trees	Total age; years	Average height growth in inches
A.....	Flat.....	Western yellow pine	182.4	51	20	9.1
A.....	SW Slope....	Western yellow pine	80.1	21	20	4.1
B.....	Flat.....	Western yellow pine	114.2	100	18	6.3
B.....	SW Slope....	Western yellow pine	88.2	36	18	4.9
C.....	Flat.....	Western white pine	75.5	12	17	4.4
C.....	NE Slope....	Western white pine	85.6	100	17	5.0
D.....	SW Slope....	Western yellow pine	74.4	12	17	4.3

3-0 plants was 22 percent on the south and 12 percent on the southeast face of the hill. For 1-2 stock it was 27 percent and 14 percent in the order given, the south face falling close to the west with 26 percent survival. The results are clear-cut in that these critical sites, as indicated by the soil tests and field soil-moisture tests previously discussed, were the determining factor in low survival and rather slow growth. In the matter of relative height growth no constant or significant differences are evident. It appears from this series on the three exposures that the southeast is the most precarious or exacting. The underlying rock may have some influence on the soil moisture relations.

The measurements obtained during the autumn of 1932 of series A, B, C, and D were made on the dominant trees regardless of original size classes. In several of the plantations 50 or more dominant trees were not available.

Records from the plantation measurements in the autumn of 1932, which are summarized in Table 17, repeat and confirm the earlier results with western yellow pine in showing better growth for series A and B on the flat than on the southwest slope. On the flat, plants of series A averaged 9.1 inches in annual height growth from the time of planting, and those on the southwest only 4.0 inches; and plants of series B averaged 6.3 and 4.9 inches. In series C, with western white pine, those on the northeast aspect show

an average height growth of 5.0 inches and those on the flat 4.4 inches over a period of 18 years. Of the white pines set out on the flat, only 12 survived out of 100. In series D, western yellow pine planted on the steep phase yellow pine site at 2a, the few surviving plants averaged 4.3 inches in height growth from 1915 until the end of the growing season in 1932.

Summarizing the results from the planting tests it appears that the results have confirmed, in a large measure, the natural selectivity of the species for given sites expressed earlier in the seeding tests; in that western white pine survives and grows better on soils with more nutrients and improved moisture-holding capacity, and that western yellow pine takes the lead on warm, dry sites with porous and somewhat impoverished soils. These planting tests have gone a step farther than the seeding experiments, since they show a definite correlation of survival and growth of western yellow pine with soil quality and nutrients; a superior development under the most favorable edaphic conditions on the flat, intermediate on the southwest slope at Station 2, and poorest on the steep phase situation at Station 2a.

It appears that the results obtained by the seeding tests and corroborated by the planting experiments have told the story better than any other set of data. Reduction in evaporation, as effected by decreased temperature and wind and by increased humidity, resulted in higher soil moisture, denser vegetation, more abundant organic material and nutrients, which in turn favored establishment and development of mesic species, especially western white pine, on protected sites, and caused its elimination from exposed aspects. In a similar way we may trace the selection by other species of their proper habitat within the succession. This selection of the most suitable location is accomplished during the very first and second years in the life of the trees. However, on intermediate sites, the more mesic species may invade and remain semi-suppressed for a long period of time and begin more active growth leading to dominance upon the elimination of more xeric species from the stand.

The order of secondary plant succession in northern Idaho, as determined by this field study of habitat requirements of the species, is from western yellow pine, through western white pine to the red cedar-hemlock climax.

Western larch has a place in the western yellow pine stage under more favorable moisture conditions, and grand firs occurs in the Douglas fir stage under the same conditions.

SUMMARY AND CONCLUSIONS

A study was initiated in 1912 at the Priest River Forest Experiment Station in northern Idaho, seeking to determine and evaluate site factors governing the re-establishment of temporary forest types of the secondary forest succession following forest fires, logging or other denudation.

Subsequent to general forest fires, which occur periodically in this region and which are very destructive, reseeding and natural return of a forest takes place by stages passing from the intolerant and xerophytic trees to the more permanent, tolerant, and moisture-demanding species.

The investigation embraced a study of the climatic and edaphic factors and an analysis of the soil with a view to evaluating the mechanical, physical, and chemical properties. Responses of artificially-sown native seedlings and planted trees formed a part of this study.

Several well-equipped weather stations were therefore located on a flat bench in larch-Douglas fir forest, on a southwest western yellow pine slope and on a northeast aspect within the western white pine type. Other secondary stations were chosen and the records for the main stations continued over a period of 5 years.

The results obtained from this study are briefly summarized as follows: air temperature relations show higher daily and seasonal maxima on the southwest aspect with a longer duration of temperatures favorable for growth than at the other points. Conditions were almost as favorable at the station on the flat, but the northeast aspect shows the least extreme in the maxima. The minima of the air temperatures were lowest on the flat both winter and summer and highest on the northeast slope. From these relations it follows that the greater ranges and the danger from frost is more acute on the flat than at the other points.

Soil temperatures reflect and follow the trend of the air temperatures, but diverge far more at the surfaces and in the upper soil stratum than at the lower levels. The absolute maximum of surface readings were, on the southwest aspect, 125° F., on the flat, 100°, and on the northeast, 95° F.

The southwest aspect which supports western yellow pine is characterized by a shallower snow cover, which is also of shorter duration than on the other sites. This site is also favored above the others by higher maximum air temperature in summer and a longer period of growing temperatures. The soil moisture reaches more critical minima and remains at dangerously low points for extended periods in summer, and wind movement and evaporation are more pronounced than elsewhere. The opposite is true for the northeast aspect, while the flat falls between these two.

The soils on the northeast slope and at situations where the mesic species grow contain a greater clay and silt fraction and higher capillary and other moisture-retaining qualities than those occupied by the xerophytic western yellow pine. These "mesic" soils show also a higher wilting coefficient and contain larger percentages of nitrogen, organic material, and phosphorus than the soils of the exposed aspects. In all of these relations the larch-Douglas fir site appears to be intermediate.

Soils of the more sandy flats which become occupied with larch and Douglas firs are ordinarily not sufficiently improved in physical properties

to favor the growth of western white pine, cedar, and hemlock. These areas will therefore remain in larch and Douglas fir indefinitely, while the more favorable soils are reclaimed by species of greater tolerance and moisture requirements.

Seedlings which were raised from seed on the different sites expressed, by their germination during the first two seasons and by their survival and height growth to the end of the fifth year, a conformity to the already existing forest trees which had seeded in after the fires of 60 years ago, in that the white pine survived only on the northeast aspect, and the western yellow pine was practically the only species out of six which survived on the exposed southwest slope.

This same tendency was found to hold true also in the plantations of western yellow pine and western white pine; the former was not planted on the northeast aspect, but the white pine survived and grew far better on the northeast slope than elsewhere, it being a total failure on the southwest site and gave very poor results on the flat.

These results demonstrate an early selectivity of the native species for their more suitable environmental conditions which is expressed primarily through their survival and later development rather than their germination, for germination of the western white and western yellow pines may take place on all of the aspects and on different surfaces. The failure of the mesic species to survive the peak of the hot and dry first summer on exposed sites and the elimination of xerophytic species by fungus growth, lack of light, and competition during the early part of their existence bring about the distribution which we have endeavored to explain.

It appears that the edaphic conditions to a large extent control and determine the order or stages in the progression of the temporary types, especially through factors of soil, temperature, soil moisture, and water-holding capacity. But these characters are to a great extent the products of climatic factors, which vary for both the exposed and for the protected aspects. On the flats and benches, however, the type of forest which forms a part of the succession depends in large measure upon the condition of the soil and its ability to hold moisture throughout the critical part of the summer.

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