SECTION XIII

THE CLIMATIC FACTORS

Light. The Douglas fir will grow in about one-fourth of the full light in adjoining open areas, although under these conditions its development is retarded, and the more shade-enduring species, such as western red cedar, western hemlock, and Sitka spruce (Picea sitchensis) have the advantage.

The inability of Douglas fir to thrive in diffused light makes it incapable of forming an understory. This characteristic is a disadvantage to the tree in retaining its position in the forest, for the more shade-enduring species crowd out the Douglas fir and often completely replace it in the stand; but it is an advantage from a commercial standpoint, for this inability to withstand shade results in early dying of the side branches, so that the tree cleans itself sooner than if this were not the case. On favorable sites, where the stands are dense, clear boles begin to form at 30 to 40 years of age, and at 40 to 50 years of age clear boles as high as 40 feet may be found. These characteristics illustrate the importance of a complete stand of young growth and the advantage of an even-aged stand. The relatively greater height growth of Douglas fir during its early years helps to maintain it. Because it demands an abundance of overhead light, it produces the tallest and straightest stems in dense pure stands or in mixture with the more shade-enduring species.

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

On good sites the favorable soil and abundant moisture enable Douglas fir seedlings to endure more shade than on poorer sites. The same conditions also favor increased survival and growth of the shade-enduring western red cedar and western hemlock, with the result that they often crowd out the Douglas fir. (21).

Carlos G. Bates of the Rocky Mountain Experiment Station has done a good deal of work on Douglas fir. The studies of light requirements are especially interesting. The summary of his results is as follows:

1. Seedlings of eight species of conifers were grown under artificial light comparatively rich in the longer wave-lengths of the visible spectrum, and varying in intensity from 55.5 per cent to 1.2 per cent during the first six months, and from 16.6 to .4 per cent during the last five months of the exposure. Approximately the same adjustments were made except at the termination of the 11 months test.

2. At the end of the 11 month period, seedlings of Douglas fir were surviving in light intensity of 0.77 per cent of that of noon sunlight on September 20, and those of Norway pine in an intensity of 2.3 per cent. Pinon pine, white pine, and Englemann spruce required one per cent or less, while bristlecone, ponderosa and lodgepole pines ranged from 1.2 to 1.9 per cent. Since there is a ratio of 3:1 between the most tolerant of the species here considered, it can hardly be questioned that there are important differences in the photo-synthetic efficiency of trees as closely related as the members of the pine family.

3. The comparatively low values tolerated, may be ascribed to the quality of the light available and to its comparatively long duration each day. In any comparison of experimental with natural conditions, both duration and intensity should be taken into account.

4. Pinon and other larger-seeded pines grew less vigorously than the small-seeded species in the weakest light in which each survived. The bearing which this may have on the major results is not clear. Only in the case of pinon, is it evident that life was maintained at the expense of the food absorbed from the seed, so that this species must be placed higher in the scale than its actual position indicates.

5. The height of seedlings surviving was not visibly affected by the light intensity, a fact which gives rise to the belief that when shading appears to stimulate height it is because the only available light is overhead, and because the conditions which produce shade are also likely to decrease the transpiration demand.

The root lengths and branches were markedly reduced in weak light, suggesting that seedlings may readily succumb to unfavorable soil conditions when the light intensity is great enough to permit some photosynthesis.

7. From the experiment we gain the impression that in the forest, light is not likely often to be the limiting factor in the survival of seedlings, since light intensities of less than two or three per cent are not often encountered. While most of our data take no account of the lack of longer wave lengths in the diffuse light which is sometimes the major supply of seedlings under the canopy, total-energy measurements recently made by the writer showed values of 10 per cent under canopies so dense that apparently all seedling growth has been inhibited for years. Furthermore, there was scarcely an hour in the day when, at a given point of observation some direct rays of the sun were not filtering through. It is therefore quite evident that in most instances in which rooting vigor and domination of root-space

or ability to make good use of a small moisture supply, are almost certainly the determining characteristics. It is not irrelevant to mention that a study of the water requirements of the same species led to essentially the same conclusion, namely, that the struggle between species is a struggle dependent on the ability of the species to make growth with the minimum use of water, and that the relative photosynthetic capacities of the species are an important element in this struggle. (7)

"Dead shade," i.e., the shade of logs, stumps, and debris, is more favorable to seedling growth than the shade of weeds and brush because it provides the same protection against evaporation, sun, and frost but does not compete with the seedlings. For the first few years of a seedlings life, the brush cover (if not too dense) is helpful because of the indirect benefits resulting from its shade. After the brush cover is well established however, the presence of this competing vegetation appreciably retards seedling growth and also prevents new seedlings from coming in. (24)

Temperature. Douglas fir is apparently adapted to severe climatic conditions in the Rocky Mountain region and on the east slopes of the Cascade Mountains of Oregon and Washington.

However the fast-growing Pacific-slope form of the species
does not bear exposure to severe cold. In winter the cold dry east winds sometimes kill the trees out-right and often kill the growing tips, especially on the east side of the trees. Such conditions are particularly injurious to young trees and either retard growth or kill the seedlings.

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

The length of the growing season in the Douglas fir region is variable, and the seedlings have apparently not become adapted to this variability. Often late spring or early fall frosts cause extensive injury to young growth. If frosts occur after growth has started or before the buds mature, the buds, - particularly the terminal buds,- suffer. Height growth is checked or completely stopped for one or more seasons, and the bushy seedlings, so common up to

4 or 5 years old are formed. If the terminal buds are killed by frost, the lateral or adventitious buds develop and it may be three or more years before a leading shoot is formed. The actual killing of young growth by frost is not common, but the death of seedlings as the result of heaving by frost is often extensive. The principal disadvantage resulting to the tree, from its inability to withstand frost, is the loss of its place among its competitors. Western hemlock and western red cedar are often found uninjured by frost that has killed the immature buds of Douglas fir. When in mixture with Douglas fir, these species take advantage of the retardation of Douglas fir and overtop it, thus eliminating it from the stands.

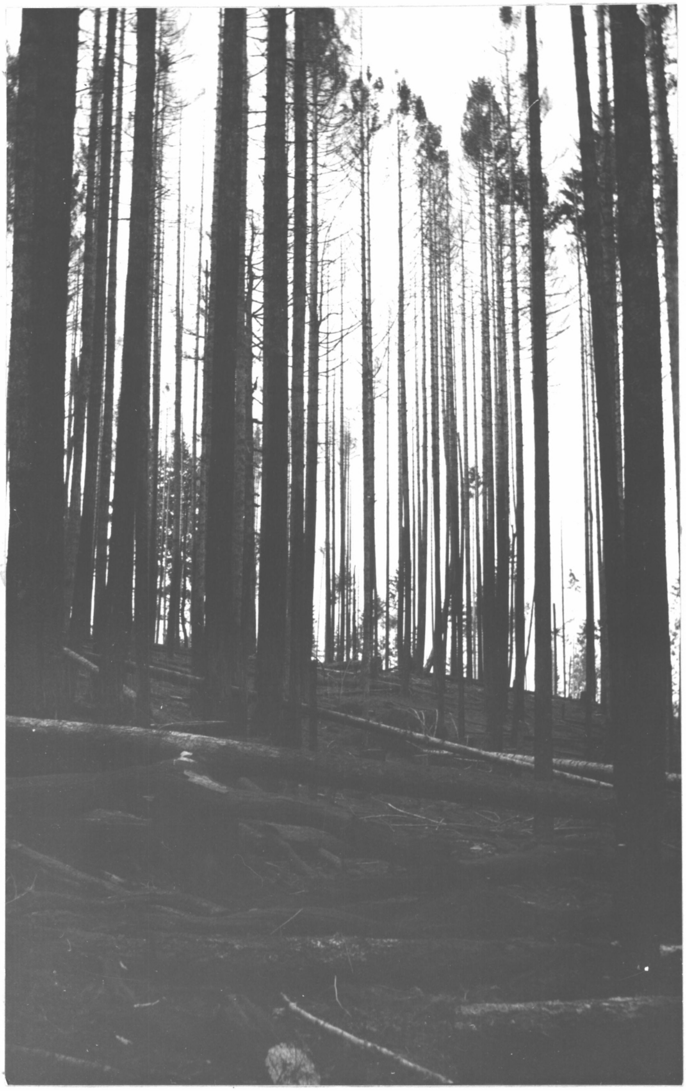
Heat injury consists of cooking the cambium usually just at the soil surface. Injury may begin when the surface soil (upper 1/8 inch) attains a temperature of about 123 degrees F. if the seedlings are less than a week old, and death may follow if this temperature is continued long enough. As seedlings grow older, they become more resistant, some surviving temperatures as high as 150 degrees F. Late spring frosts kill tender seedlings by freezing, and injury starts at air temperatures of 30 degrees F. or lower; late fall and winter frosts cause seedling loss by "soil heaving."

Temperature is thus seen to be the most important factor in seedling survival. It kills seedlings directly through excessive heat and cold, and indirectly through frost heaving, and through drought. Maximum and minimum surface soil temperatures cause most of the seedling losses.

Color of the soil was found to have a pronounced effect on the maximum surface temperature attained. Dark soils, particularly those with charcoal (from fire) on the surface, developed much higher surface temperatures than light colored soils. With an air temperature of 90 degrees F. (in a weather shelter) the temperature at the surface of a yellow soil was 132 degrees F., whereas similar soil covered with a thin layer of burned duff and charcoal had a surface temperature of 150 degrees F. (Both in full sunlight.) The highest temperature recorded in connection with this study was 166 degrees F. It occurred on a blackened surface when the air temperature was 102 degrees F. Since seedling injury may occur at temperatures anywhere above 123 degrees F., it is not difficult to understand how the increased temperature that results from blackening the surface soil by slash burning may be responsible for great seedling losses.

It was found that shade is of importance not only to keep the soil surface cool in the daytime but to keep it warm at night as well. During the summer months of the five consecutive years of this study maximum air

FIGURE 15



Logged with no thought of future productivity and then burned. Note the dark color of the area - conducive to high temperature.

temperatures recorded in a weather shelter on a typical logged-over area varied from 52 degrees F. to 112 degrees F. In a strip adjoining, of old-growth Douglas fir timber, corresponding temperatures averaged 10 per cent lower. On a fully exposed surface maximum soil temperatures averaged 49 per cent higher than the air. Under brush cover they averaged 29 per cent higher, while under virgin timber they were practically the same as the air. While too much shade may be as detrimental as no shade, it can readily be seen how shade may prevent great seedling loss by moderating surface temperatures. Minimum air temperatures as low as 28 degrees F. were recorded in late spring in this study; shade was found to have a pronounced effect on these temperatures, and the lack of it often resulted in increased seedling losses. It was found that when the air temperature was 32 degrees F., the temperature of fully exposed mineral soil surface was likely to be about 4 degrees lower, while under the shade of brush or debris, it was likely to be 4 degrees higher. With temperatures thus far experienced, most of the seedling loss has been on bare mineral soil surfaces.

A study of the relation of temperature to cover at Oregon State College is very interesting.

Temperature in Degrees

Location	Air		Surface of Soil	
	Centigrade	Farenheit	Centigrade	Farenheit
Under Oak	21.5	71	23	73
In open	26	79	45	113
Under Fir	19	66	18	64

The high temperature in the open shows the importance of shade. The temperature of 113 degrees obtained on a comparatively cool day is very significant, for, according to various authorities, a temperature of 119.5 to 122 degrees will cause heat lesions on the stems of tender young seedlings. (Exposed south slope)

The exposure of Douglas fir to a heat of 220 to 240 degrees F. for five minutes resulted in 4% germination. Exposure for five minutes at 240 to 260 resulted in 0 germination. Germination period -- 112 days.

In nature, fatal temperatures are reached in seedlings only at the base of the stem, where for a few millimeters above and below the soil level, the living cells may be killed. This heat injury ranges from mere discoloration on the sunny side of the stem to the complete constriction and killing of a whole ring of tissue. Heat injury is difficult to distinguish from "damping off." The edges of the lesion are more sharply defined in the case of heat injury, however, and the damage occurs under very different conditions.

The temperature in the base of a seedling is largely influenced by the amount and position of the shade cast by the cotyledons and true foliage.

The degree of injury suffered by heat lesions varies with age as the hardening of the stem tissues (development of epidermis, endodermis, xylem, and compression of the cortex) reduces the tendency to lop over and hinders the entrance of pathological organisms, which several investigators have indicated as the probable cause of death following only moderate injury. (3)

Water. The importance of soil moisture in the success of Douglas fir reproduction was first brought out by F. B. Noteslein in 1912. He established sixty 10 by 10 foot reproduction plots, regularly scattered over the entire area before it was cut, and studied the influence of light intensity, soil moisture at 1, 2 and 6 inches, organic content of the soil at 1 and 2 inches, and soil temperature at 6 inches, upon the character of the reproduction.

It was determined that Douglas fir will reproduce successfully in a light intensity of 8.5 per cent. In a stand having an average light intensity of 27.24 per cent, reproduction averaged most abundant at points of least light; but Noteslein was satisfied this simply meant that there was sufficient light everywhere under such a stand, which is comparable to the present control stand, but that in the openings where light is intense other conditions were unfavorable.

Soil moisture was found to decrease with increase of light. At the same time, Douglas fir reproduction was greatest at those points having the greatest soil moisture. All facts indicated that soil moisture not only is a more potent factor than light in controlling reproduction, but that it is the controlling factor.

The total soil moisture varied directly with the amount of organic matter in the soil, while the available soil moisture varied inversely with it. The relation between the amount of humus and reproduction is uncertain, but the facts brought out indicate the probability that there is a point up to which humus increases water capacity more than wilting coefficient, and is, therefore, favorable to reproduction, but beyond which point it has the reverse effect.

Because of the usual long summer drought period in Benton county, soil moisture content is a factor of considerable importance in seedling life. Unlike some other regions which receive a large proportion of their total rainfall during the summer months, this county often has little or no rain over a three months period. Seedling mortality from drought is sometimes caused by a gradual decline in soil moisture as the season progresses, but at other times it is the result of only a few, dry hot days.

FIGURE 16

Douglas fir coming in as a result of this oak leaf mulch.

Occasionally, when the soil moisture content is already low, a single hot day is enough to dry the soil below the point fatal to the seedlings.

Studies at Oregon State College, of moisture content of soil under the oak trees, as compared with samples taken in the open, show an interesting relationship.

Group	Depth	Per cent of Moisture
Oak	0"	19.9
"	6"	24.0
Open	0"	12.1
"	6"	20.8

These measurements were made on May 28, and they show that even this early in the season, marked differences have developed in the soil moisture content. Already the surface soil in the open has reached the wilting point for plants and unless the little trees are able to keep ahead of the decreasing moisture by rapid root penetration they will be unable to survive. (28).

The results of this study show the effect partly of shade under the oak and partly of mulch furnished by the last year's oak leaves upon the ground.

Moisture conditions on an area on which the slash is burned are quite different from the moisture conditions on a similar area which has not been subjected to fire. In the first place, the large amount of dead shade is removed, which shade reduced the temperature of the surface soil and the consequent rate of evaporation. The live shade, brush, is usually killed, but will sprout up in a season unless too severely burned. Live shade, however has one disadvantage - moisture is needed to support this brush which furnsihes the shade.

In the second place, the soil is so darkened as to greatly raise the surface temperature, as explained before. The exact effect of this difference in surface temperature is difficult to measure when applied to soil. However, by using Livingston porous cup atmometers with white and black bulbs, one will get a difference in evaporation rate which might be compared, though not directly, with the evaporation rate from a light and dark surface soil. During some periods the evaporation from the black bulb may be twice as great as that from the white bulb in the open. The difference is not so pronounced when the bulbs are shaded but there is even then greater evaporation rate from the black bulb.

The evaporation from the atmometers is not exactly applicable to that from the surface soil, but merely indicates that there is a difference between the evaporation from the different colored soils of considerable extent. Acres of land in Benton county are literally covered with charcoal as a result of fire, so the evaporation must be considerably greater than from unburned land. (17).

The forest in Benton county has from 40 to 70 inches of moisture per year. This precipitation varies widely for different locations. The mountains towards the coast enjoy the maximum, and elevation tends to experience increased rainfall. In the lower parts of the county along the river about 42 inches of rain is normal. (41)

Douglas fir can be found in almost any location in the county but its successful establishment and growth are largely controlled by moisture. Site studies have been made in different localities in the Douglas fir region and the soil moisture correlated with the establishment and survival of Douglas fir seedlings. The ability to extend its root system 6 or 8 inches deep during the early part of its first growing season is an important factor in perpetuating Douglas fir. When it is in competition with such other species as western red cedar and western hemlock, which produce shallow-rooted seedlings, it often is unable to survive where the other species fail.

Records of soil moisture taken in 1919 on the flat river bottoms and south slopes in the Cispus burn near the Tower Rock Ranger Station north of Mount Adams, demonstrated the ability of the Douglas fir to resist the adverse conditions of severe sites. On the south slope the moisture in the surface soil reached a minimum of 0.18 per cent in July and did not go above 0.86 per cent in August. The wilting coefficient of 2-year-old Douglas fir seedlings was found to be 1.25 per cent for this soil. These data show conclusively that seedlings could not live in the surface layer of the soil, because the available moisture was below their requirement. At a depth of 6 inches, however, there was sufficient moisture for growth throughout the season.In the flat river valley where the soil is a silt loam, the surface soil contained 0.19 per cent of moisture in July and 0.09 per cent in August. At a depth of 6 inches the soil contained 11.45 per cent of moisture in July and 9.32 in August. Obviously, then, seedlings that have root systems which penetrate to a 6-inch depth before July of their first season, may become established in this region. (22).

These extremes of soil moisture are readily explained by the records of soil temperature and evaporation. The surface soil on the south slope reached a maximum temperature of 128 degrees F. in July and 135 degrees in August. From July 15 to October 1, evaporation records with the Forest Service evaporimeter showed an evaporation of 1,070 cubic centimeters on the south slope as compared with 690 c.c. on the flat. The striking effect of evaporation on these sites is shown by the evaporation from open water surfaces exposed only to vertical radiation as, for the most part, are masses of vegetation. On the south slope, 15.1 inches of water evaporated from an open water tank during the month of August, while only 1.8 inches e evaporated on the north slope, and 6 inches on the flat.

Even if the soil moisture is equal in two localities, the soil texture may have a decided influence on the availability of the moisture to the plants, as expressed by a marked difference in the wilting coefficients. This difference would not influence the types if the soil moisture were the same at all depths. But the fact that the surface soil often dries out, while the soil at a depth of 6 inches remains moist on protected slopes and dries on exposed slopes, changes the type and gives a decided advantage to the seedling with a deep root formed early in its development. In its early root growth the western yellow pine forms the dry-slope type in the border zone of the Douglas fir forest region. It is very noticeable that wherever a ravine or spring keeps the south slope moist, the north slope species are found. Evaporation, then, is one of the chief factors in the establishment of the seedlings, for, while the different slopes often get about the same amount of precipitation, there is such a marked difference in evaporation that the exposed slopes dry out while the north and protected slopes remain moist. On the fully exposed, cut-over area, the soil always had less moisture at a depth of 3 inches than soil under mature Douglas fir timber or under brush cover. At a depth of 6 inches the soil moisture content on the three areas was about equal. At a depth of 12 inches, however, there was more moisture in the soil of the fully exposed area. Occasionally the moisture content of the soil at the 3 inch depth dropped below the wilting point for Douglas fir seedlings on the fully exposed area, but this did not occur under brush or forest cover. Contrary to the findings in many other forest regions, practically all moisture available during the summer months is water stored in the soil during the preceding season and raised to the surface by capillarity; the top 6 inches of soil was almost always found to be dryer than the lower strata.

Because of the usual summer drought period in this region soil moisture is a factor of considerable importance in seedling life. Unlike some other regions which receive a large proportion of their total rainfall during the summer months, most parts of the Douglas fir region get little or no rain over a 2 to 3 months period. On the area studied the average annual rainfall is 85 inches, but during 5 years the greatest rainfall in July and August amounted to only 0.76 inch. During three of these years no rain fell in July. Seedling mortality from drought was sometimes caused by a gradual decline in soil moisture as the season progressed, but at other times was a result of only a few dry, hot days. Occasionally, when the soil moisture content already was low, a single hot day would dry the soil enough to kill many seedlings. As might be expected, seedling mortality was greatest on the logged area which recently had burned.

Since soil moisture frequently is the factor controlling the survival of young seedlings, it follows that the presence of other vegetation may sometimes present serious competition for the little moisture available. These studies indicate that for the first few years of a seedling's life, the brush cover (if not too dense) is helpful because of the indirect benefits resulting from its shade. After the brush cover is well established, however, the presence of this competitive vegetation appreciably retards seedling growth and also prevents new seedlings from coming in. (24)

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Wind. Wind is a factor in evaporation upon broad open places, on slopes where it has a strength that grows. Especially is it a factor on the ridges and peaks. Douglas fir is very much affected by the wind in several ways. Wind proves valuable in disseminating Douglas fir seed It is often disadvantageous in bringing in seeds of competing species and it does great damage in the newly opened stands as a result of logging and fire. Wind polinates the cones of Douglas fir from the pollen clusters. Wind is often a terrible factor in the crown fires of the region and often the westerly winds off the ocean have brought rain at a critical time in fire fighting. South-west winds and those from the west in Benton county bring us our moisture. Wind is said also to be of great utility in the forest in conveying fresh supplies of carbon dioxide to the foliage. (42).

Wind is to be considered when contemplating a cutting in a forest, for wind is a factor on exposed slopes through its drying action. That the rate of drying varies greatly with wind velocity is obvious to any observant person. Experimental evidence as to quantitative relationship is rather variable. Hansele (quoted by Helbig, 1930) found the soil evaporation nearly proportional to the wind velocity at rates from still air to nearly 30 m.p.h. Harris and Robinson (1916) found an enormous increase of evaporation as wind velocities increased up to 5 m.p.h., but between 5 and 20 m.p.h.

FIGURE 17

This stand is yielding to the force of the wind Cutting was too heavy for future productivity.

little increased evaporation showed. Bates (1911) showed that with a 20-mile wind, evaporation from a Piche evaporimeter falls to only 40 to 50 per cent of the evaporation in the open within 1 to 2 tree heights of a wind break. Some effect is felt as far as 20 tree heights in the lee of the windbreak. With a 5 mile wind the effect is less striking and is felt only about 5 tree heights away. (4).

The distance to which Douglas fir seed may be carried by wind has been a point of controversy for years. To shed light on this problem the Forest Experiment Station in Portland, Oregon, carried on rather extensive experiments under the direction of L. Isaac. Seed traps were set on logged-off land adjacent to green timber. Here on slightly rolling topography, seeds were caught in traps a half mile from green timber; but seedfall, in sufficient quantity to be a factor in restocking, did not extend beyond 1,000 feet from green timber.

Another series of tests was made by releasing seed from a box kite at an elevation of 200 feet above level ground. Counts on the snow indicated that seed released in a wind velocity of 7 miles an hour fell in greatest density at 1,000 feet from the point of release and the maximum distance to which it was carried was 1,800 feet. Seed similarly released in a 23-mile-per-hour wind fell in greatest density 1,600 feet from the point

FIGURE 18

Douglas fir edging into a field.

Bracken fern is also spreading in this area.

of release and made a maximum flight of 3,500 feet. The occurrence of reproduction on sample plots on logged-off land substantiates these measurements of seed flights. Also the reproduction survey of the Tillamook burn made during the summer of 1936 showed that area to be adequately seeded for an average distance of 10 chains from green timber and lightly seeded beyond that point during the two years that have elapsed since the fire.

From what information is available, it appears safe to assume that an area will seed for an average distance of a quarter of a mile. However, air movement is so variable that no positive distance of seed flight can be set up for a specific area. Douglas fir seed falls at a rate of approximately 2 miles per hour, and the distance it may be carried may be greatly affected by local topography as well as horizontal air currents. Recent aeronautical meteorologists have brought out that rising air currents from 1 to 10 miles per hour frequently occur on warm slopes. Should falling seed encounter a rising air current that exceeded its rate of fall, it might be carried unbelieveable distances. Similarly, falling air currents may bring seed to the earth much more quickly than normal fall. The occurrence of reproduction at long distances from a source of seed, which has puzzled investigators in the past, may be explained by these vertical air currents. (24)

The measurement of natural seed fall (seed trapping) from a timber edge shows that from the shorter wood lot type of trees the bulk of the seed falls within 100 feet of the timber, but from a heavy crop, sound seed in goodly numbers (8,000 to the acre) may be expected 900 feet from the edge of the timber.

From a light crop, such seeding cannot be expected for more than half that distance. A comparison of dissemination from the short(150 foot) timber with that of a similar crop from the tall(210 foot) timber indicates that the seed of the latter will be carried twice as far as that of the former.

The heavy fall of seed close to the timber is evidence that most of the seed is shed during periods of low wind velocity. (25).

Douglas fir seed (as well as that of its principal associates, cedar and hemlock) ripens in late August; The cones open, and much of the seed is released then. With damp weather, the cones partially close and when they open again on dry days more seed is released. In this way the dissemination of the seed is continued through the fall and early winter. An appreciable amount of good seed can be found in the cones in mid-winter.

The light-winged seed is bourne away from the parent tree by the wind and is subject to the wind's vagaries. The seed dispersed on still days naturally alights close by. In high winds it may fly far. The maximum distance at which seed trees can do effective seeding is not known. It depends, among other things, upon topography, the season, and the amount of seed dispersed. Crusted snow could easily increase the distance that winter sown seed may be carried by wind. (33).

Soil Organisms. The number of lower plants and animals which are temporarily or permanently housed in the soil and draw nourishment from it is quite astonishing. Nine-tenths of all insects spend some time in the soil. Their harmful activities through devouring of roots (grubs), damage to seedlings, unfavorable physicochemical influences on the soil, etc., are exceeded by their profoundly beneficial activities.

Darwin was the first to call attention to the importance of earthworms in working over the soil. By their burrows, which penetrate to a maximum depth of 7 m., they open up the lower layers of the soil. They grind up large amounts of earth with their principal food, which is decomposing plant material. The excreta of worms are deposited occasionally within their burrows but usually on the surface of the ground in little spiral heaps. This material, as D'Auchald has ascertained, is richer in nitric acid and calcium carbonate than the original earth. For this reason the soil reaction of the worm excreta shows a somewhat lower H-ion concentration.

Earthworms in this manner not only further the loosening and crumbling of the soil, but they render the nutritive substance of the soil more easily available for plants and thereby increase the store of nutrients.

They are most abundant in nearly neutral soil and are rarely found in soils with an acidity higher than pH 6.

<u>Soil Fauna</u>. Compared with the activity of earthworms, the importance of insect larvae, ants, centipedes mites, etc., in the soil is probably very small, but very little is definitely known on the subject.

According to the food habits of soil animals, Buckle distinguishes earth eaters, meat eaters and plant eaters. The meadow and grazing soils contain at least 50 per cent of plant eaters while tilled soils are inhabited mainly by meat eaters. This fact is probably related to the circumstance that, unlike meadow and grazing lands, the tilled vegetation does not cover the soil throughout the year.

An abundant microfauna, composed of infusoria, rhizopods, rotifers, and nematodes, inhabit the soil and especially the root layers down to a depth of 15 cm., and participate in the processes of soil formation. These are to be considered of great importance in the formation of humus. A high development of the protozoan fauna corresponds, as a rule, to an impoverished bacterial flora. The development of bacteria and their activity are affected unfavorably by the presence of large numbers of protozoa.

A very important disease of young seedlings is known as "Damping off." It may be caused by many fungi, among which is Pythium, which inhabit the soil. "Damping off" is more prevalent in nurseries because of the ease of spread in the thick growth and also because of the neutral or slightly alkaline condition of the soil in most nurseries. It can be checked to a large degree by the application of acid to the soil which does not harm the seedlings since they are naturally acid-lovers. (Douglas fir). In the burns thickly covered with a new growth of first-year seedlings we have a comparable circumstance to that found in the nursery bed. The fire has neutralized the soil and the damp weather in the germinating period in the Douglas fir region adds to the growth of the organisms. However, it thrives on organic matter and there may not be an abundance of this in the burn, certainly not if it is recent. Isaac has estimated the amount of Douglas fir mortality to "Damping off" at about 5%.

<u>Soil Flora</u> The microflora of the soil plays a much more significant role than the animals in soil economy. This flora is composed of countless bacteria, fungi, and algae which live preferably in the root layer of the soil and are exceedingly active there. Their significance is indicated by their function of nitrogen fixation, as well as by the fact that they make more available many substances already in the soil but difficult of assimilation

by higher plants.

Microorganisms not only contribute to the increase of the food resources of the soil but also release inorganic food materials. Thus, by their mediation, the cycle which transforms dead organic waste into assimilable plant food is completed.

In the forest the best nitrification is shown after cutting, when nitrification and decomposition of litter are favored by light.

Along with nitrogen-oxidizing processes we always find, also, nitrogen-reducing activities. The living conditions for both processes seem to be similar. The soil conditions favoring one or the other of these groups of bacteria determine whether construction or destruction of nitrates shall predominate. Very acid soils without herbaceous cover, in conifer forests, have decided tendency toward dentrification. (10).

The insects injurious to Douglas fir reproduction have not been positively identified. The extent of their damage can be judged by the observations of Alexander, indicating an average loss of 10% due to insects, and Isaac, indicating a loss of 16% with the greatest part of the loss occurring in burned over areas.

Wild Animals Douglas fir seed is particularly attractive to rodents. Most of the seed matured during years of light or medium seeding is consumed and the production must spring from the surpluses of heavy seed years. Rodents are also very important in the injury to the young seedlings. Isaac places rodent injury of seedlings third in the causes of their death. The white footed mice are sometimes a problem. In one instance they consumed practically the entire season's crop of newly germinated seedlings on sample plots. During the past season (two years after the fire of 1933) they were found numerous on the great Tillamook burn area.

Rabbits do some injury to seedlings by nipping the buds, but they are not usually of great importance in the Douglas fir type. Deer do some browsing but do not injure reproduction under ordinary circumstances. It is quite common in small saplings to find trunks from which the bark has been stripped by the deer. This is due to the itching of the "velvet" on the horns of the buck. During this period he often gets down on his knees and works his antlers against the trunk of the tree, relieving his discomfiture as he removes the troublesome velvet. The tree is not always killed but often this is the case.

Birds. It might be said that man is largely indebted to bird life for the ability to grow any timber at all. When one considers that birds eat from two to five times their weight in food each day when young, the amount of insects eaten is seen to be enormous. As a rule birds do not live very long, but they live fast. They breathe

FIGURE 19

Bark beetle infestation as a result of burning. The picture shows the chopped up bark as a result of the woodpecker. This friend of the forester prevents spread of the beetles by going into the infested cambium after them.

rapidly, have a higher temperature and more rapid circulation than other vertebrates. This is a fortunate circumstance, since to generate the requisite force to sustain their active bodies, a large quantity of food is necessary and, as a matter of fact, birds have to devote most of their waking hours to obtaining insects and other foods. (Quoting H. W. Henshaw, former chief of the U. S. Biological Survey.)

The hawks are fairly plentiful in the Douglas fir region. Their chief diet is rodents. These include rabbits, mice, chipmunks, gophers and others. They also feed extensively on insects and to a lesser extent on other birds.

The poorwills, nighthawks, and swifts, especially are beneficial. They devour myriads of insects found over our forests and in the forest itself.

The sapsuckers are truly damaging to the forests. (44).

The woodpeckers are great aids to the preservation of our forests. Woodpeckers are apparently the only agents which can cope with certain insects enemies of the forest. For this reason, if for no other, they should be protected in every possible way. Excepting for a single species, these birds rarely leave any conspicuous mark on a healthy tree except when it is affected by wood boring larvae, which are accurately located, speared and devoured by the woodpecker.

Perhaps the two species of swallow that enjoy the forest most are the tree swallow, and the northern violet-green swallow. The former is a transcontinental species while the latter makes its summer home in the Pacific North-west. These birds feed while in flight the same as night-hawks and swifts. Their food, therefore, consists entirely of insects found in the air. They fit into the foresters conception of useful economic factors by searching the air over the forests for food.

The jays, ravens and crows will take a great variety of food. This food consists of fruit, insects, grain, seeds and the eggs and young of smaller birds. From seventeen to twenty-six per cent of their food consists of insects. They also destroy young mice and rats. They seem to do much good as well as much harm. They seem to have a definite place in the scheme of nature's balance.

Henry W. Henshaw says of our warblers: "They occupy no uncertain place in the list of our useful birds. Preeminently insectiverous, they spend their lives in the active pursuit of insects. They begin with the eggs, preying upon them whenever and wherever found and continue the good work when the egg becomes larvae, and when the larvae becomes the perfect insect.

They are especially valuable in this respect because of the protection they lend to the forest trees, the trunk bark and foliage of which they search with tireless energy.

Their efficiency is vastly increased because the many different species pursue the quest for food in very different ways. While some confine their search chiefly to the trunks and large branches and examine each crack and crevice in the bark for eggs and larvae, others devote their energies to the twigs and foliage, scanning each leaf and stem with eager eyes. Still others descend to the ground and examine the litter and grass for hidden prey. Nearly all are adept at catching insects on the wing.

The quantity of animal food required to drive the avian engine is so great that it is no exageration to say that practically all the waking hours are devoted to food getting. What this never ceasing industry means when translated in tons-weight of insects, it is impossible to guess, but the practical result of the work of our warblers and other insectiverous birds is that we still have our forests and shall continue to have them so long as we encourage and protect the birds."

The members of the thrush family include such well known species as the bluebirds and robins. The most delightful song of the deep forest is that of the hermit thrush. Its associates, many other thrushes, are also known for their songs. They are typically forest birds, spending most of their time on the ground, seeking their food beneath the litter of leaves and twigs.

Since we see that birds in the forest are in reality working hand and glove with us in this business of forestry it is up to us to aid them in their work. Maintenance of food supply, allowance of certain areas for nesting, protection wherever possible against the destruction by fire, and many other methods can be used to aid the birds in their work for forestry.

Tame Animals. Coniferous trees are not highly palatable for domestic stock, but it is true that tender growth of Douglas fir is often nibbled by sheep and to some extent by other animals.

Seedlings in the main are injured in four ways: (1) trampling, (2) rubbing, (3) browsing, and (4) by burning off of the logged-off lands by stockmen to secure better feed for their stock. Seedlings from 6 inches to 5½ feet seem to be the ones suffering from grazing. The seedlings under 6 inches have such a tremendous mortality from other causes as disease and fungi that any damage done by grazing is negligable.

The younger seedlings are damaged more by trampling, while those above two feet are injured by rubbing, and those of all sizes are damaged to some extent by browsing.

The trampling is characteristic more of goats and

FIGURE 20

Sheep browsing on Douglas fir.

Bracken fern is rapidly reducing the value of this area for grazing purposes.

sheep as they usually travel in bands. They not only injure the seedlings by the mechanical action of trampling but also by digging the soil away from the roots and so exposing the root system to drying out.

The damage caused by rubbing is more characteristic of horses and cattle. This is generally seen on older seedlings. Either the leaves may be rubbed off, or the bark itself may be injured, or the trunk bent over so far as to permanently injure the tree.

Browsing of the young stuff always does harm, as, along with the needles, generally the terminal buds are eaten. Goats are especially hard on reproduction because they have the habit of eating practically anything. Sheep are next in order of damage done to reproduction by browsing and then come cattle and horses.

An intensive study is being made at the Pacific Northwest Forest Experiment Station on the effect of grazing on the Douglas fir reproduction. This study was started in 1925. Some work has also been done on the McDonald forest at Corvallis, Oregon. The plots at the Experiment Station were established on logged-off land, some of which had been burned and some of which had not. The plots at Corvallis were located in a variety of conditions. In both cases check plots were established alongside the samples.

Both these studies show that grazing animals of all

FIGURE 21

Sheep grazing - no reproduction

kinds certainly harm Douglas fir reproduction.

In general, cattle and horses use a grass range to better advantage than do sheep or goats. By grass range is meant range which has a dominant forage of grass, as distinguished from weeds and similar forage such as we find on burns and high mountain areas. Sheep relish tender green leaves and also the seeds of many grasses, but they eat sparingly of the coarse dry stems and leaves. Cattle on the other hand, consume a much larger portion of the coarse grass. Sheep will eat part, or all of most weed species on closely grazed ranges and often prefer the succulent weed to true grass. On the other hand, only a small percentage of weeds are palatable to cattle. Both cattle and sheep eat considerable browse but sheep care for this type of food much more than do cattle. Cattle do reach higher than sheep and get more forage from high browsing. For sheep to use brush range of large area, the brush should be in an open enough stand to enable the sheep to move about readily. They will gradually work their way through, and fully use small areas, however dense the brush, if it is palatable, unless the area is too wet. This is sometimes the case where willow browse occurs in wet meadows. Cattle will use dense brush range, but do not prefer it. Cattle are apt to become footsore more rapidly than sheep or goats and this is to be considered if the area is very rocky.

FIGURE 22

Brush coming in as a result of burning for grazing purposes.

The distribution of the water supply is not only an important factor in the full utilization of forage but it is also important from a silvicultural standpoint. The forester will find more damage in an area where the water is limited as to source. With water well distributed over the area, danger from trampling, browsing, and rubbing is greatly lessened.

Sheep can generally go from three days to several weeks without water, depending upon the amount of succulent feed, the temperature, and the amount of rain or dew. Cattle need water every two or three days, depending on the same factors, but they are in the habit of drinking much oftener where water is readily accessible.

Distribution of salt on the area may keep the animals better located and so result in less damage to reproduction.

We often find in western Oregon the same land being used both for timber production and for grazing. As a result of running transects through the various pastured forest lands and from other observations we have come to the conclusion that the two uses of the same land is the height of folly. Either the land should be set off to grow timber or it should be used as grazing land alone and treated as such.

The damage to reproduction is very evident in the study. It isn't a case of killing the young trees but rather that of stunting them and making them unfit for timber production. Time after time on a logged over area one will find young Douglas fir seedlings coming in where protected by brush, and again, by location. Along the trails and more frequented areas, trampling and browsing is holding the area in a semi-reforested state. On one side of a fence may be seen an adequately reseeded and growing area while on the other side little or no reproduction is visible. From our observations we have decided that the two uses are incompatible to good management of land.

The habit of burning the land over when the brush starts coming in is another oft-practiced policy. This of course kills the seedlings and gives the brush a start in the use of the ground.

Pearson has done quite a good deal of investigation in this field (Grazing and Reproduction): "Full crops of timber and forage cannot grow on the same ground at the same time. Wherever there are forests and grazing animals there is conflict. Where conditions of climate and soil are favorable to tree growth it is usually the forest that prevails. Very little forage can grow under a forest that approaches full stocking. It is only through the aid of fire and lumbering that grazing can gain a foothold in the forest."

If timber production is truly the major objective, forage production on timber lands can scarcely be even a secondary objective for then whatever grazing is afforded must be regarded as purely incidental and temporary. Grazing must be subordinated to such an extent that there will always be a substantial margin of safety on the side of the forest. This will usually result in incomplete utilization of the forage.

The solution of the grazing problem should follow constructive lines. Distinction must be made between true forest lands and lands chiefly valuable for grazing. On the latter range management should be developed to a high degree. On the former there should be no attempts to increase grazing capacity, but rather to decrease it by replacing grass with trees.

One difficulty in people realizing the fact that the two industries cannot go hand in hand is the fact that grazing is decidedly advantageous in most burned over areas in reducing fire hazard.

Some idea of the reduction of fire hazard through grazing use will be gained from the average utilization of the vegetation found on 94 chain plots periodically examined in the experiment with sheep on the Columbia forest. Fireweed, a highly inflammable plant which averaged 40 per cent of the stand, was consumed 74 per cent; grasses and sedges were used 83 per cent; bracken though mainly trampled, was used 14 per cent, and blackberry considered of doubtful edibility at the start, was grazed 59 per cent. The average use of all vegetation removed by stock was 56%.

FIGURE 23

Old burn showing dried remains of fireweed - very inflammable.

Man. In Benton county one might well say that every acre of the land has been affected by man. In the early days the Indian burned the hills and lowlands to drive game and to keep the areas open so that game might increase. Later the settlers came in and established stock ranches on the immense grass areas. Laws against fire were necessary because of danger to property and lives. As the result of laws we find the ecological aspect of the county changing more and more with the passage of time. Whole hillsides that were covered with grass for ages now began to take on the green Douglas fir.

Land in the higher reaches that was timbered but had been burned to keep out the brush now began to have an understory of brush and reproduction. Forest litter began to accumulate and the soil layers of duff and humus were formed. Instead of a bare floor one finds an inch or so of material in various stages of decay. Douglas fir for reproduction purposes prefers the bare soil for many reasons and so the reproduction began to be composed of other species also instead of one species, Douglas fir. Cedar, hemlock, white fir and in the more moist and shady locations, alder and maple began to creep in.

The forest is still in a process of change and it is to man's advantage to study his practice in the forest so as to gain the maximum from the area.

Fire And The Soil. "Fire is particularly destructive on thin, sterile soils. On deep bottom-lands rich in plant food the effect of a fire on the soil is not nearly as severe as it may be on a soil lacking already in depth and quality. Studies have shown that the litter and partially humified material on the forest floor may contain 2 per cent or more of nitrogen." (2)

The forest tree depends for its nutrition largely upon the materialization of the litter dropped upon the forest floor. Most of the humus material and the humification processes occur on the top of the soil. As the process continues some of the soluble humus is leached into the top soil, which is very porous and absorptive to a depth of 6 inches or more.

When fire enters the forest, both the litter and the humifying material are consumed at once. Even the humus in the immediate surface soil may be partially burned out. In the area burned over, the humus content of the soil is low in the immediate surface and increases with depth. In the unburned area the humus content of the soil surface is high, and decreases with depth.

The immediate effect of burning is to produce a rather liberal supply of plant food. This is favorable both to soil organisms and to plants growing on the soil Just after a burn which destroys the over-growth there is likely to follow a rather profuse vegetation of wild grasses and herbs that produce excellent humus materials. Even legumes may volunteer. It is well known that clover starts easily when seeded in the ash after a burn. What represents several years of leaf fall, however, is consumed by fire in a few minutes. In fact there may be 10 tons or more of litter and humus material per acre on the forest floor. In old forests there are several times as much. More than 100 tons per acre has been reported. (31)

In timber that is so dense as to prevent growth of grass, the renewal of so much humus material would require several years. The litter fall per season probably does not exceed 2 tons and may be considerably less. Repeated burning, therefore, must soon result in a condition where there is no longer any organic materials in the soil to humify. Nature's method of renewing forest soils then becomes inoperative. Only one result can follow. Impoverished soils must lead to reduced tree growth, through lack of nutrients, reduced moisture capacity, and generally unfavorable conditions. It would seem rather dangerous to conclude, therefore, that because the immediate effect of burning is helpful the general practice even with controlled fires repeated frequently would be beneficial to the soil." (16).

A factor that seems to be often overlooked by foresters when talking of slash disposal by burning or the effect of burning of any kind, is the loss of that great wealth of soil organisms that are to be found in the natural soil and which are so beneficial in most cases. One of the big factors in flood control is the maintenance of the earth in an absorptive condition. Upon the forest floor when burning is kept out, one finds numerous pores down into the earth, made by organisms of various kinds. Earthworms, beetles, insect larvae, ants, centipedes, and smaller forms, all do their part in maintaining this sponge-like action of the forest. The loss of these organisms by fire in conjunction with the loss of the humus and litter decreases the absorptive power of the forest immensely. These organisms make plant food available also as discussed under grazing.

The result of exposing the forest floor by fire is the filling of each tiny hole with minute particles carried in solution by the first rains. After that the water has a tendency to run off rapidly.

Fire and Seed Stored in the Duff. For many years foresters and lumbermen labored under the impression that Douglas fir seed stored in the duff from year to year remained viable. These men believed that this immense supply of stored seed was but waiting for the removal of the parent crop when it would germinate and furnish the new forest. "Three series of tests extending over nine years were made by the Northwest Forest Experiment Station. These tests were made by burying the seed under natural conditions and later testing them for germination. These indicate rather definitely that the Douglas fir seed that falls to the forest floor and is not consumed by birds and rodents either germinates or decays within one year. On cut-over lands sample plots examined annually over a long period of years show that the amount of new reproduction fluctuates in accordance with the cone crop of the previous year. During the past year (1935) a reproduction survey was made of the great Tillamook Burn. This showed that an abundance of 1934 reproduction was found where there were either green trees present or where 1933 cones were not consumed by the fire and were either still clinging to the dead trees or were found on the ground. Where there were no green trees or 1933 cones present the reproduction was conspicuously lacking.

Although there may be conditions in nature under which some Douglas fir seed will remain viable for more than a year after falling, it appears safe to conclude from the foregoing evidence that most of the reproduction springs from the seed of the previous years cone crop." (24)

In case of logging without provision for seed trees the importance of the last seed crop is at once clear. This last seed crop may be the only source of the new forest. Of course if there is an adequacy of seed trees left to seed in the area, then it isn't so important. If the the area is burned to reduce the slash hazard the chances are that the last seed crop will be consumed in the blaze.

Most Douglas fir slash fires completely consume the duff and burn down to the mineral soil. Experiments have shown that moist heat over 180 degrees and dry heat over 200 degrees will so injure the seed as to reduce germination to less than 1%. With heavy slash on the ground and anything like decent burn it is folly to expect seed to survive a slash fire.

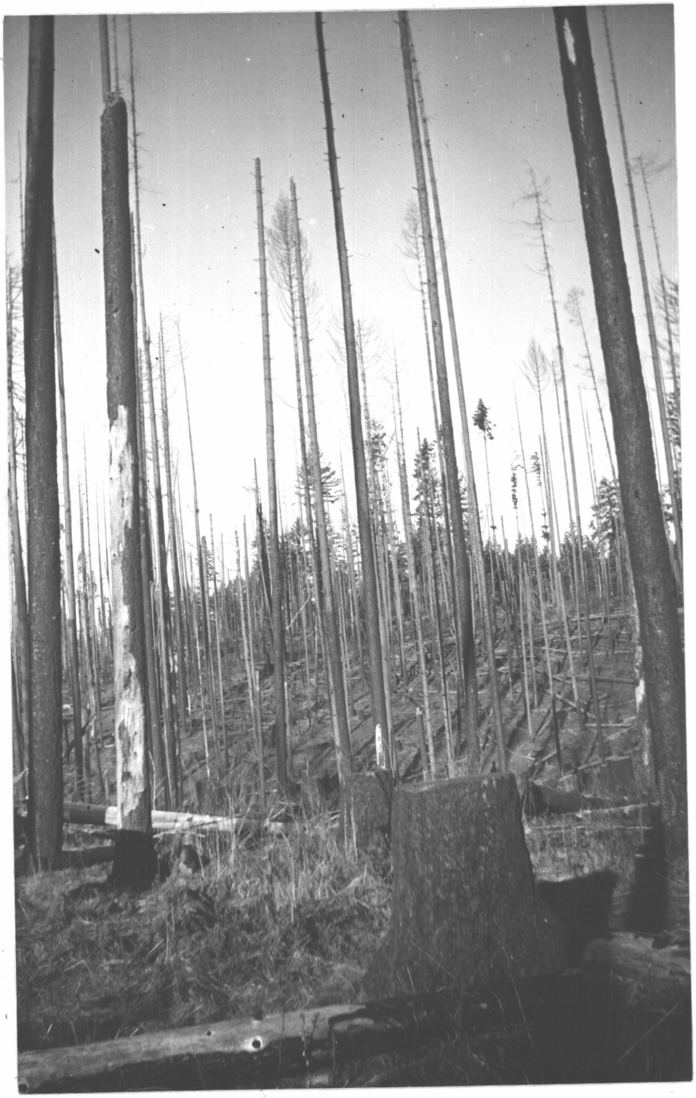
Fire and the Effect on the Remaining Standing Timber

Of course any small trees on a slash area are killed by the fire as it sweeps through the slash. Sometimes there are isolated patches that escape but for the most part small material is killed outright. There are large areas in Benton county that are existing evidence of the heat generated by a slash fire, for entire stands of Douglas fir poles can be seen standing lifeless on the burns. If the area had large, thick barked trees on it these probably survived and some few of the poles may live through. So to the damage caused by the loss of seed must be added the loss of this standing young material.

Fire and the Resulting Immediate Vegetation.

The vegetation coming in after a slash fire is usually rather distinctive. This cover develops irregularly but certain species of plants can usually be found. Liverworts and mosses which cover the soil and annuals and perennials, such as fire grass (Agrostis

FIGURE 24



Result of logging and broadcast burning. These trees might just as well be alive and growing.

hiemalis), fireweed (Chamaenerion augustifolium), everlasting (anaphalis margaritacea), thistles (cardus), milfoil (Achillea), bracken fern (Pteris aquilina), and other species with wind-blown propagules are the first to occupy the area. As the burns grow older this association gives way to shrubs such as raspberry (Rubus strigosus), hazelnut (Corylus americana), and huckleberry (Vacinum macrophyllum.) This shrub association if not further disturbed will eventially give way to vine maple (Acer circinatum), alder (Alnus oregona), and this in turn evolves into the sub-climax forest, Douglas fir.

The rather profuse vegetation which follows after burning, is a producer of excellent humus materials. Nitrification is stimulated and this, coupled with the burning, increases the soluble mineral nutrients in the soil for some time after burning.

Fire and Reproduction. When a slash fire burns an area it may affect it in several ways.It may be a light fire and so leave part of the forest floor or it may burn all of the material and so result in an area with no duff at all. If the fire merely sweeps over the area it may not kill all the seed and a good stand of reproduction may result. The condition of the slash as to moisture, the humidity of the air on the day the fire is burning, the topography and the wind all enter in. A large majority of the slashing fires do a clean job and therefore kill all of the seed from the previous years crop. In that case the area must be regenerated thru seed from trees left on the area, thru cones left in the tops of trees by the fire, thru wind-blown seed from adjoining sources or thru the efforts of man in reseeding or in replanting the species. Many times the seed supply is destroyed; the seed source is also destroyed and the result is a bracken fern waste, a brush patch or a new area composed of other more or less worthless vegetation from a forestry standpoint.

The fire does eliminate the competing vegetation and gives an immediate supply of available nitrogen and ash components. This favors the reproduction of Douglas fir against the other plants. Where the area is clean burned and there is sufficient seed trees it often regenerates in a dense stand of Douglas fir. There are however many factors to be considered, including shade, color of soil, available moisture, etc.

Douglas fir will germinate in almost any situation into which the seed chances to fall, if there is sufficient moisture and proper temperature. Generally speaking, germination is better on bare mineral soils but samples have shown that the seedlings will germinate and grow on humus and rotten wood, often extending their roots 6 -8 inches in the humus or rotted wood before reaching mineral soil. Alexander, in a study of reforestation in the Grays Harbor area, found that Douglas fir gave best germination on areas which were slightly shaded. The percentage of reproduction occurring in each class was as follows:

Bare mineral soil	10.5
No shade, spring burn	6.1
20% " " "	29.0
50% " " "	24.7
75% " " "	18.1
Level aspect, bracken	9.6
Southern aspect, "	0.0
Northern " "	2.0

Observations indicate that dead shade creates the best conditions for seedling survival because the surface is shaded without a loss of moisture in creating the shade; whereas live shade may rob the seedling of light, moisture, and ground space to the extent of injury.

The fact that Douglas fir may prefer a bare mineral soil for germination has been used repeatedly by the exponents of slash burning. In so exposing the soil, however, grave changes are wrought in the productive capacity of the soil and in the physical factors which influence the survival of Douglas fir seedlings.

One of the physical factors is the change in the color of the ground as a result of charcoal formation. In his work on the study of natural reproduction, Isaac, of the Northwest Forest Experiment Station, has made a series of observations on the relation of air temperatures to surface soil temperatures on different colored soils. He found that an air temperature of 80 degrees F will develop a surface soil temperature on yellow mineral soil of 116 degrees F., on gray mineral soil of 123 degrees F., and on black charcoal soil of 129 degrees F. As the air temperature increases, the surface temperature on the black surface shows a greater deviation from that on the other two surfaces.

However, a surface temperature of 129 degrees F. has been shown to be high enough to cause heat lesions and kill the seedlings, but an air temperature of only 85 degrees F. developed this soil temperature of 129 degrees F. Higher air temperatures than this are of frequent occurrence in the Douglas fir region. Therefore the Douglas fir seedlings are liable to killing by heat injury on even the yellow soils, more so on the gray soils and certainly on the black soils. This study also brings out the importance of some shade.

This injury of heat, caused by solar isolation, is a cooking and killing of the cambium at the ground line. A number of experimenters have conducted tests to determine the minimum surface soil temperature which will cause this cambium injury. Frank Kaufert at the Wind River Nursery determined that surface temperatures up to 123 degrees F. would cause lesions on seedlings up to 18 days old, temperatures up to 125 degrees would cause lesions up to 21 days old and temperatures up to 130 degrees F . would cause lesions on seedlings up to 30 days old. Toumey of Yale has set the dangerous point for coniferous seedlings to 122 degrees F. Munch of Germany has found that a surface temperature of 129 degrees F. will quickly kill coniferous seedlings. Jacob Roeser, Jr. of the Rocky Mountain Experiment Station also conducted experiments. He says: "Temperatures up to 120 degrees F. seem unlikely to cause stem injury to seedlings of Douglas fir. Douglas fir is very slow in the first year to develop resistance to heat. Any development of this species under conditions of intense isolation seems impossible." We can say then, that a surface soil temperature of about 125 degrees F. is usually fatal to young seedlings.

Fire and Erosion. In addition to the water actually absorbed by the forest litter there is a restraining influence which is all too often overlooked. (23) Thus, while a heavy litter cover might actually absorb and so hold against capillarity an inch or more of water, the litter by means of its arrangement and its porosity holds more water, under exceptional conditions, probably several times as much. The litter becomes a veritable sponge and permits the soil to absorb water.

Newly fallen litter material is not as effective in restraining the flow of water over or through it as that which is partially decomposed. Fresh needles are slightly resinous and water flows off as from an oiled surface. However, as decomposition takes place and water can enter the fibers, surface tension and cohesion tend to hold the water.

Recent and as yet incomplete detailed investigations by the California Forest Experiment Station (31), indicates that the surface run-off, from forest soils from which the litter has been removed is from ten to thirty times greater than from soils with a complete and undisturbed mantle of forest litter. The litter prevents the beating drops of rain from so re-arranging the soil particles that they clog up the pores in the soil and cement the channel openings. To put it another way, with a litter mulch the rain does not disturb the surface by its beating action, the water is kept clean at all times as the litter and raw humus strain out any pore-clogging material, and the water reaches the soil by percolation, rather than directly, and in such a fashion that the water can be absorbed at a much greater rate than from a bare soil. The rain-drops do not usually strike the soil direct and thus destroy the granules, as they tend to do in burned over areas. When this protective covering is removed by fire or any other agency, erosion takes place.

The results of the California studies above referred to indicate that the litter is perhaps the most important element of the forest in determining the distribution of rain into the superficial run-off and into seepage. Still further do they show that the function of the forest litter to absorb water is insignificant in comparison with its function to maintain the percolation capacity of the soils. This operates to keep the water, reaching the soilthrough seepage channels, clear, even during the most intense, beating storms, whereas the superficial run-off on areas devoid of litter soon becomes muddy by picking up small particles in suspension, which were filtered out at the surface as the muddy water percolated into the soil.

In these experiments one set of plots was burned clean of its litter for each of three types of soil. In the experiments the superficial run-off from the burned surface was greatest in every instance from the litter covered surface. Litter was more effective on the fine-textured soils than on the coarse-textured soils.

Under forest litter the absorptive capacities of the soils changed remarkably. The forest litter continued to function for all durations of rain in approximately the same fashion. Superficial run-off from burned surfaces was muddy while that from litter covered surfaces was clear. Differences in eroded material was far greater than that in the run-off tests. The rate of erosion did not increase uniformly with the increase of total superficial run-off. The fine-textured soils yielded the greatest amount of sediment.

To determine the effect of the percolation of both clear and muddy water through soil columns of otherwise uniform nature, a laboratory experiment was carried out. In this experiment clear water was passed through four tubes of soil for 10 days to establish the relative characteristics of the material used. Thereupon muddy water was applied to two of the tubes, the water passing through the other two remaining clear. The percolation rate of the first two tubes dropped from a rate of 1.000 cc. per hour to 500 c.c. in four hours, and then continuously in a parabolic curve to a percolation of 90 c.c. per hour. After another 10 days, muddy water was applied to the last two tubes of soil through which clear water had passed at a uniform rate, and the behavior of these soils was the same as that of the first two.

This experiment demonstrated the fact that muddy water percolates through sandy loam soil only at a fraction of the rate of clear water. Suspended particles are filtered out at the soil surface where they form layers of fine textured material which determines the rate of percolation capacity of the soil column. The formation of a fine textured layer at the surface of the bare soil as a result of filtering suspended particles from percolating water is, therefore, concluded to be the decisive condition which increases the superficial run-off from bare areas. This fact indicates that the most important function of forest litter is to maintain the natural characteristics of a soil profile by keeping the rain water clear --a function which was for a long time overlooked, or if considered at all,only with inadequate conception of its significance. (29)

Bates (5) says as a result of the Wagon Wheel Gap experiment that the measurable detritus carried by the stream in question after the forested headwaters had been denuded, increased 25% in amount. Most of this increase was secur ed during the flood quarter.

In another report on the same experiment, (6) he lists the effect of denudation upon run-off and erosion. In prenudation years the average annual precipitation on watershed A (undisturbed) was 21.03 inches; the average run-off of A was 6.08 inches and that of B (denuded) 6.18 inches. In the post denudation period the average precipitation was 21.16 inches, and the flow of A 6.20 and B 7.26 These figures indicate an excess flow from B of about .96 inches for the average of seven post denudation years. During the prenudation period the average annual silt load of A was 691.5 pounds and that of B was 568.5 pounds. In the second period the silt load of A was 477 pounds and that of B 3, 340.1 pounds. The ratio of B to A increased from 0.822 to 7.082 or about 8½ times.

Meginnis (31) mentions the results of studies by the Southern Forest Experiment Station of the United States Forest Service. For a flood period, Dec. 15 to Feb. 15, it was found that an average of 62% of all the rain fall on cultivated land immediately rushed off the surface, carrying with it soil toteling 34 tons an acre. An average of 54% of all the rain falling on barren, abandoned fields flowed off immediately. During many rains more than 75% and as much as 95% of the rainfall ran off these two classes of land and contributed to the quick filling of stream channels. In contrast, an average of 98 per cent of the rain falling on scrub oak woodland was absorbed, only 2% running off. On unburned broomsedge field and virgin oak forest an average of less than one-half of one per cent of the rain flowed off the surface.

The result of the run-off studies are fully in accord with those of less formal observations of surface run-off from various land types in northern Mississippi. A single shower of even moderate intensity is usually sufficient to start a rush of soil-laden waters from every gully and cultivated field, while the most torrential rains are seldom seen to produce more than an insignificant surface flow from areas protected by a vegetative cover. The run-off from wooded ravines is usually insufficient to sweep leaf litter and other debris from the drainage lines.

Toumey (42) cites an example of experiments in the San Bernardino Mountains from which the following table was compiled:

Precipitation and run-off during December, 1899.

Area of Catchment basin.	Condition as to cover	Precipitation	Run-off per sq. mile	Run-off in per centage of precipitation.
Sq. miles		Inches	Acre-feet	Per cent
0.70	Forested	19	26	3
1.06	"	19	73	6
1.47	"	19	73	6
.53	Non-"	18	312	40

The Burbank flood in Los Angeles county, California, illustrates both the influence of a vegetative cover on run-off and erosion, and the high costs involved in removing detrital material.

In the fall of 1924 the Burbank watershed of 704 acres was burned. No intense storms occurred during 1924 and no great increase in run-off or in erosion was noted. In the spring of 1925, a storm which reached high intensities for only about 10 minutes, at times as high as 2 inches per hour, visited this region. The total rainfall for this entire storm was only 1.07 inches but as a result of it 25,000 cubic yards of material came off the watershed and buried part of the city of Burbank. Property damage was exceedingly high. The cost of removing the detritus was estimated at $25,000 to $50,000. Eighty per cent of the precipitation came off as run-off. Adjacent canyons, on which the cover was not recently disturbed, were also visited by this storm, but showed no immediate surface run-off and no movement of eroded material. (28).

It might be said then, that anything that disturbs forest cover adds to the erosion problem of that area. Fire is the most widespread and one of the most destructive disturbances of the forest cover. Even the lightest fire does damage. During the first few years after logging, a hillside, clear cut or severely cut, will unquestionably erode somewhat. The skid trails produced by power handling of logs have been found to start erosion. Over-grazing disturbs the forest cover chiefly by the consuming of more of the herbage of the more palatable plants than they can withstand, and by increased trampling. Studies by the Forest Service show that there are many areas now producing not more than 20 to 30 per cent of the forage of which they once were capable, and under such conditions erosion is usually severe.

In Benton county we are in a comparatively new country. Man hasn't been working his will on the forest soils long enough possibly for the real values to be known. After viewing a few hillsides that have been burned broadcast, however, one realizes that the problem of erosion is with us. It should be possible to manage the land so as to do away with this soil loss with its attendant evils.

FIGURE 25

One stage of succession

Douglas fir coming into oak

SECTION XV

SUMMARY AND CONCLUSIONS

SUMMARY

After studying the many factors that influence Douglas fir reproduction we can only come to the conclusion that they all dovetail together. In any particular situation it might be possible to pick the limiting factor but in considering the county as a whole it is necessary to stress the importance of all of them.

Temperature seems to be the cause of the highest mortality among the small seedlings. Water seems to be the limiting agent where the reproduction has been unable to gain a hold on the ground.

The true forester must recognize that while these two are probably the most important, he must not lose sight of the other factors. He must be a coordinator "par excellence". The soil can be built up to the point of highest productivity; the soil organisms will help when handled properly; the rodents must be considered in reference to seed supply; wild animals of larger size may be a serious hindrance to the well-being of the forest; birds on the whole are very beneficial and should be considered as friends and given their proper place in the scheme of things; man can be the cause of much grief, if thru ignorance, his ways are harmful. Management must integrate these various agencies so that the highest possible good to ownership will be the result.

The result of grazing studies points to the beneficial action of grazing in lessening fire hazard. The beneficial results are forced into the background,however by the damage caused to the future productivity of the forest. We can only come to the conclusion that land use must be the theme. If the land is grazing land it should be used for that purpose only. Any other system of use will result in lowering of the forage value of the land and the depreciation of the growing timber. The trees on grazed land are, in many areas, useless except for cordwood. If they are close enough to prune naturally, the forage is negligable. The use of land for the two purposes is to be discouraged.

The use of fire in the present manner seems doomed. The only excuse is the reduction of fire hazard and this reduction is open to question. The soil must, in the future, receive more attention from foresters. Fire is hard on the soil directly and thru the following evils: drying out, increased temperature, and erosion. We must find substitutes for its use, and partial burning with more intensive protection, seems to be the cure. With more and more men looking to the government for jobs, it is only reasonable to suppose that increased protection can be looked for. With an enlarged forest agency or agencies forest roads can be built, areas broken up into smaller units with fire-breaks and a better detection and suppression system put into effect.

Erosion is present even in Benton county. When mentioned we see smiles of incredulity but the fact remains that when we can see evidences of any erosion the soil is being washed away far too fast for it to be built up at the same rate. We have seen evidences of this erosive action. They are not pronounced as yet but the soil is in most cases rather shallow and we should conserve what we now have before it is too late. Compared to the great canyons of other states and regions, our fingers of erosion and sheets of silt seem insignificant; the fact remains, that our soil has not the depth to produce such noticeable affects, and solid rock will not grow lumber for profit.

SECTION XVI

RECOMMENDATIONS

RECOMMENDATIONS

1. Considering the importance of the forest cover in Benton county and the wealth of industry resulting from the forest, it seems an economic mistake for no one to be in charge of the coordination of the resources with the market productivity. We recommend the appointment of a County Forest Agent to establish a county Forest Office for making studies of all sorts pertaining to the wealth of the forest lands, and advising the many entrepreneurs, engaged in the production of lumber, in the proper methods of cutting and milling the Douglas fir.

2. There seems to be a wide field for further study pertaining to the factors influencing Forest land productivity. The college Forest school has made many studies heretofore adding to the store of facts accumulated by the forestry profession. We have a few more studies that might be worked on in the future:

a. What is the difference between growth of Douglas fir on sterile soil and the growth on soil rich in soil organisms?

b. How much would it cost per acre to prepare the soil for Douglas fir regeneration by means other than fire, and what would this preparation consist of?

c. What would be the expense and benefit of rough reservoirs constructed on the headwaters of the streams flowing thru the forest stands?

d. What is the effect on the soil of opening the stand to the sun?

e. What does bracken fern do to the soil content and consistency?

f. What is the effect of wild blackberry, ocean spray, haselnut, sword fern, thimbleberry, wild rose, and many other annuals and perennials on the soil composition, water content, shade, etc.?

g. Can an area recuperate to full productive capacity, in terms of Douglas fir, without an intermediate period of brush, weeds, grass etc., growth.

h. Would it be advisable for a mill owner to replant cut-over areas that may be hard to regenerate?

i. Can severity of cut be correlated with slope so as to minimize erosion damage?

j. What is the actual damage done to a second-growth forest by erosion because of unscientific cutting? What elements of the soil are washed out? How is organic life affected? What plants are favored and why?

k. How long does it take for an inch of soil to be built up under a Douglas fir second-growth stand?

l. Can the soil grow Douglas fir in pure stands without intervals of relief afforded by another cover?

m. How can a study be made to prove that burning of pasture land is only a temporary benefit and is detrimental in the long run?

n. Would an increase in the proportion of hardwoods in our Douglas fir forests be in keeping with good forest management in all its phases?

m How much nitrogen is actually lost in Benton county when an acre of slash is burned? How much is liberated for present consumption? What is the reserve for future growth?

p. How can moisture be conserved in the forest and what will be the effects of this conservation?

q. Can foresters, by planting methods, reduce wind-throw in later years without reduction in quantity of wood?

r. How does humidity affect forest transpiration?

s. Could Benton county change the climate to any great extent by planting of water-tapping trees in the fence-rows and neglected corners of the lowland farms?

t. What is the effect of light intensity on the transpiration stream?

u. Does light intensity ever prohibit Douglas fir reproduction and can the Photo-tronic-meter be used to advantage in studying results of light as affecting reproductions?

v. How much light does poison oak require for successful invasion of the forest or is this purely a water relation?

w. What is going to be done to make the public fire-conscious and how could a constructive program be put across for building up this fire-consciousness. What would this program consist of?

x. How much would it cost per mile to construct roads thru the timber stands to serve as summer patrol roads, and also as protection breaks in case fire is started?

y. What would the cost of skeletal planting of the large bracken fern areas, so as to procure a stand of Douglas fir reproduction of proper density in fifty years?

z. What is the value of one acre of every fifty or so given over to wild-life as seen in increased protection from insects injurious to the tree and as repaid by increased sales of licenses and complementary sports goods and supplies?

a.. What is the actual damage caused by rodents in destruction of seed and reproduction.

b.. What are the most beneficial birds within the Douglas fir region.

c.. What is the benefit of the hawks and owls in reducing the rodents?

d.. What is the cost to a forest owner of raising deer, and is the return in proportion to the cost?

e.. What determines a heavy seed year in Douglas fir?

f.. What is the proper method of thinning Douglas fir? When should it be done in the life of the stand? What would be the cost? What would be the result in the mature crop? How would it affect the soil?

g.. What is the proper crown density to be maintained in a second-growth Douglas fir forest. to allow for proper utilization of the crop without sacrifice of the remaining stand, qualified as to location?

h.. How does the removal of Douglas fir bark affect the growth?

i.. Can brush be killed out by intensive grazing by cattle and horses?

j.. Can brush be killed out by grazing sheep and goats if the area is not over-stocked?

k.. How can a study be made to show that repeated burning or burning of any kind increases the proportion of brush on the area?

l.. Could we institute correspondence with European schools of Forestry to encourage interchange of notes between students so as to build up knowledge of silviculture? It seems that Europe must have gone thru a good deal of what we are now going thru in the way of fire, grazing, and erosion? Some interesting ideas might come out of the correspondence.

m.. What is the actual effect of the work of soil organisms on the earth?

n.. What are the most important forms of organic soil life?

O.. What is the effect of fire on soil organisms in its various intensities as found in slash removal burning?

p.. Can the result of fire in Douglas fir stands actually be measured in decreased diameter growth?

These are but a few of the questions that might be listed for future studies. We feel that the school should have a great wealth of sample plots set out on the McDonald forest; far in excess of the quantity of plots out there now. A student should be able to refer to the study that comes up, by going to the record of measurements as made thru the years. In time the information accumulated would be available.

The school could well afford to invest in more instruments also. Instruments for the measurement of light humidity, wind velocity, precipitation and evaporation should be of great benefit.

A far more serious interest of the students in the properties of the soil and in the changes wrought in the soil by outside influences, might yield data that would be of great benefit to the Forestry profession.

Zoology in its relation to the forest may prove to be a subject full of useful information. We do not seem to have a very adequate grounding in that subject at the present time.

If a program could be worked out to give students in silviculture a wider field of experience they might be able to do more constructive work. There is something to be said for greater exploration of the great wealth of material open to us in the west. With the building of splendid highways, and with the perfection of modern methods of travel, it would be a shame not to try to combine the theory of silviculture with the practice as we might see it in the Coast States.

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