STUDY METHODS
(Field)

The general overall plan for study called for two consecutive summers of residence in the forest of approximately ten weeks each. Additionally, several other trips of from a few days up to two weeks in duration were made at various times throughout the years. These were for the purpose of obtaining soil moisture data, temperatures, observations of snowfall and miscellaneous information. In all, approximately twenty-six weeks were spent in residence in the area.

Field Reconnaissance

In June 1959 field reconnaissance was begun by making compass and pacing traverses of roads, boundaries, section lines and other salient features. From the traverse lines, notes were made of vegetation, topography, tree growth, soil surface characteristics, and other conditions. This was for the purpose of stratifying soil and vegetation into as many homogeneous units as possible for analyses. The data thus obtained were used for making a map delineating preliminary soil-vegetation strata. From the reconnaissance data a detailed map of the traversable roads was also made. After stratification, evaluation of the plant communities from the photographs provided an additional check on the accuracy of stratification.

Vegetation Analysis

Stratification of Communities. As previously mentioned, data for preliminary stratification into plant communities were obtained from observations taken during field reconnaissance. In the preliminary stratification only the relative abundance of shrubs and trees was used as criteria. At that time, appraisal of grass and forb strata did not appear to warrant their use in preliminary stratification. The purpose of the stratification was to reduce variation within strata to a minimum and thus to both reduce the number of plots necessary to describe the forest and adjacent communities and to increase the accuracy of such characterization. Although it was desirable to base stratification on some discrete qualitative characteristic this was not found to be possible in every case. Three strata appeared to have only quantitative cover differences and probably could have been correctly evaluated as a continuum rather than as discrete communities. However, the strata were so distributed areawise that any objective attempt to evaluate them as a continuum would have been extremely difficult. These were the first three communities described below. The only significant changes appear to be in the quantitative differences in coverage of pine and juniper overstories respectively.

The following five strata were delineated from the preliminary reconnaissance data:

1. T-0. This type is composed of the most dense stand of ponderosa pine in the forest. (Figure 27A shows a stand typical of this strata.) Junipers are relatively uncommon, the understory is very sparse, and in some cases, almost non-existent. The total area included in the type is rather small but very distinctive and relatively uniform over the area which it occupies. It was in this type that heaviest cutting of timber occurred during recent harvesting operations. Most of the pine stems show the yellow bark indicative of declining vigor. Sand dunes are rare.
2. T-1. This type is similar to the previous type but is a slightly more open forest stand with a slightly heavier understory. There is also a higher proportion of the area covered

by junipers. The individual pine trees as in the T-0 type show signs of declining vigor. (Figure 27B.) Occasional shallow sand dunes are present.

3. T-2. T-2 contains a considerable range of conditions but with a less dense overstory than Type T-1. It may have a relatively heavy cover of junipers with a few scattered living pines, a slightly greater number of pines with a few junipers and as in some cases junipers with dead stumps or standing dead stems of ponderosa pine, the only indication of a pine site. The understory shrubs may be very sparse, missing entirely, or may occur in dense patches. In fact, the most significant characteristic of the type is the presence of the numerous evidences of drought and of beetle attacks of the 1920's and 30's. (See Figure 27C.) Occasional shifting sand dunes present.

4. TO-BB. To this strata belong the ponderosa pine stands of approximately the same density as T-0 but characterized by a dense understory of bitter brush (Purshia tridentata). (Figure 27D.) The pine stems indicate a much

A

T-0

B

T-1

C

T-2

D

T-0BB

Figure 27. Soil-vegetation types.

higher vigor than those of previously described types. There were a few older trees in the area but most of these were removed by the loggers. In some spots there are dense stands of vigorous black-barked, young pines. The type is located almost entirely on sand dunes of from two to ten feet or greater in depth. Where sands are shallower, bitter brush is frequently displaced by luxuriant growth of gray rabbit brush (Chrysothamnus nauseosus). Here is also found an occasional mountain mahogany (Cerococarpus ledifolius).

5. T-3. Upland Sage. A dense stand of big sagebrush (Artemisia tridentata) and gray rabbit brush (Chrysothamnus nauseosus) best characterize this type. Junipers are rarely found in it. No area was included in this if it contained any evidence of having supported ponderosa pine growth in recent times. Sand dunes are not common. (See Figure 28B.)

After sampling of the vegetation had begun and after more detailed inspections of the soil had been made, it was found necessary to define three additional rather distinct strata.

6. T-4. Lake Bed Sage. According to external

appearance the vegetation on the level portions of the old lake bed was similar to that of the slopes of slightly higher elevations (Figure 28A). However, further investigation of soil and vegetation indicated a rather distinct difference between them. The soils of the T-4 area are much more alkaline while the T-3 soils had a much more prominent and dense zone of calcium carbonate or caliche. In lake sage type, Artemesia tridentata was often displaced by A. cana. Halophitic forbs, grasses and shrubs were much more common than in the upland sage type. Blowouts and sand dunes are relatively common.

7. T-5. Idaho Fescue (Festuca idahoensis). Further reconnaissance resulted in the discovery of a small area approximately six-hundred acres in size in which a good stand of Idaho Fescue is the distinguishing characteristic (Figure 28D). For most of the area junipers are the predominate tree with only an occasional ponderosa pine. In some portions the only evidence of pines is in the old uprooted stumps. These stumps appear to be much older than those of the trees which

succumbed to the drought of 1920's and 1930's. It is probable that the dry period of 1830-1840, which nearly reached the severity of the one of more recent years, was responsible for the death of the trees since there was no evidence of fire.

8. T-6. Sand dunes. The frequent appearance of ponderosa pine on the sand dunes throughout the forest appeared to warrant a special study. (Figure 28C.) (The dunes are particularly conspicuous on aerial photographs.) For this reason ponderosa pine without bitter brush and occurring on sand dunes averaging three feet or more indepth were the subject of a separate soil vegetation analysis. There was no general area in which these constituted the most common type. They occur on an individual dune basis.

<u>Vegetation Sampling System</u> - The basic approach adopted for sampling vegetation was originally developed by Daubenmire (59). It involves use of a system of plots which are adapted in dimension to the size and area of influence of individual plants. For example, a smaller plot is used for sampling grass than for shrubs and trees.

A

T-4

B

T-3

C

T-6

D

T-5

Figure 28. Soil-vegetation types.

The procedure is begun with establishing by means of a compass, steel corner stakes and previously measured wire boundaries, a rectangular macroplot fifty feet by one-hundred feet. Within the fifty by one-hundred foot macroplot, four individual transects each twenty-five feet in length are located by random assignment. Ten plots (four feet by five feet) are located systematically along each of the random transects for shrub evaluation. For grass and forb evaluation, ten plots of one foot by two feet are located on five-foot stations along the same transects. This basic structure was developed by Eckert in collaboration with Poulton, Tisdale and Hironaka (59). The underlying assumption is that accuracy of sampling is more efficiently achieved with a larger number of smaller plots than with plots of greater size. This system of plots provides a theoretical maximum efficiency for each type of vegetation to be sampled.

Initially an attempt was made to locate macroplots by random methods. This was found to be possible only in the T-0 and T-3 types which were relatively uniform. In all others variation produced by shifting sand dunes precluded all possibilities of random location of the macroplots. As a result, it was necessary to place the macroplots in representative and homogeneous sites within each soil vegetation strata previously selected for the study.

During the first season, at each macroplot location, soil profile descriptions were made and soil samples collected by horizon for laboratory analysis. During the second season, soil profiles were described from only two to four of the pits dug in soils typical of each soil-vegetation strata.

The strata selected for sampling by each macroplot were carefully selected only after extensive reconnaissance and only if they appeared representative of the entire stratum. The plots were well distributed over each soil-vegetation type in order to provide maximum area coverage. In strata T-0, T-1 and T-2, a modified combination of systematic and random methods were used. Sub-units of from twenty-to-one-hundred acres within each type were carefully selected to represent the type. Plots were tentatively located on a map by random selection of co-ordinates. If in the field, plots were found to fall upon or included a distinct break in type such as a sand dune, mill site, skid road or others, a previously determined alternative selection was made. This did not keep all subjectivity from plot selection. The original purpose in adequately describing soil vegetation type might have been served as well by careful selection of macroplot locations by completely subjective methods.

Six plots were located in each strata. This number of replications of plant communities was considered adequate to describe modal characteristics (60). According to Eckert a minimum of four plots are necessary within each sage-bunch grass community of the high desert region.

It is obvious that both accuracy and the validity of such method of sample selection is entirely dependent upon the investigator's understanding of the ecological relationships of the plants involved. In this case the author had traversed the area for several days on foot to become well acquainted with the obvious vegetational relationships. An additional factor in favor of the efficacy of the subjective methods employed are that the plant communities except for T-1 and T-2 are distinct and readily distinguished from one another. This is primarily due to the small number of plant species present. Furthermore, as previously mentioned, the soil-vegetation aspects of the study were approached with a design which was flexible enough to permit later modification if more detailed investigation warranted.

The fifty by one-hundred foot macroplots were found to be adequate in size for the sampling of understory vegetation. Eckert (60) states that based on specific area determinations, fifty by one-hundred foot plots are accurate for the range lands of Central Oregon. In some portions of the Lost Forest area, particularly where the forest overstory was relatively dense, the variation in the coverage of the forbs and grass was high. Here extreme care was necessary in locating the macroplots to achieve a representative sample of both overstory and understory vegetation.

The total vegetation appeared to be accurately measured through the author's modification of the system described by Eckert (60) and Dyrness (59). The modification consists primarily of the addition of the wedge prism and the variable plot method of sampling tree cover to Eckert's and Dyrness's procedures. The principle of the use of the wedge prism is described by Bell and Alexander (20). The stand density in the Lost Forest is too low even with a prism factor of ten to permit an adequate measure of the area covered by tree crowns if tree boles are used as a criterion. To measure crown coverage of juniper and ponderosa pine the prism was used for a direct measurement of the crown area--ground area ratio.

To accomplish this crowns were considered exactly the same as stems and tallied if the prism displaced the margin of the crown. This proved to be somewhat difficult owing to the matching of two irregular boundaries, that is, the outer branches of tree crowns. It was found very simple to view only as one-half crowns and tally as if they were entire. Thus, the trunks and the leaders of trees provided a distinct straight line as a boundary for matching the split images. Correction for using one-half crowns as a criterion rather than entire crowns was made by multiplying the result by four.

In actual practice the observation points for evaluation of crown and stem areas were chosen to coincide with the four corners of each macroplot. The system worked extremely well in the study but would not be applicable in normal stands where crowns are closer together.

For the purpose of establishing shrub plots, four fifty-foot transects were randomly located within the macroplot, each one paralleling the long dimension of the plot. The starting point for each transect was determined by random selection of two coordinates with the reference corner of the plot serving as an initial point for the coordinate system. The shrub plots were four feet by five feet in size with the five-foot section of the transect serving as the long dimension for each. Ten of these were located along each transect. The subplots were located on one side of the line or the other by a random selection method. The other three sides of the subplots were defined with a measuring rod carried for that purpose.

The grass and forb plots were similarly located. These were one foot by two feet in size and, as with the shrub plot, the fifty-foot transect line served as one of the boundaries, and as in the shrub plots were randomly located on one side or the other of the line. The boundaries in this case, however, were delineated by a one-foot by two feet metal frame, open on one end.

Initial points of the grass and forb plots were assigned by random selection to each of the ten five-foot intervals along the transect line. Thus, one plot was located with its initial point of 0', 1', 2', 3', or 4', the next at 5', 6', 7', 8', or 9', etc. Therefore, with one plot in each five-foot interval, each transect had ten such subplots. Since there were four fifty-foot transects in each macroplot there was a total of forty grass and forb plots in each macroplot.

Frequency data were obtained by tallying each species occupying each subplot. Constancy for each species was sampled by tallying presence within the macroplot. If a plant species was tallied in any one of the subplots its presence in the macroplot was automatically recorded.

Shrubs were tallied by three height classes in the plots as previously described. The classes used were 0 up to 6 inches, 6 to 24 inches, and 24 inches and over. Total numbers of individual plants were recorded.

The percentage of area occupied by the shrubs and tree seedlings were estimated. In estimating the cover of shrubs or seedlings the spaces within each crown without foliage or live branches of an area one-tenth the total or larger, were deducted from the total coverage of the plant. Trees and shrubs rooted within the plots were recorded by size classes but only that portion of the crowns within the plot was included in the estimate of cover. That portion of crowns extending into plots from trees and shrubs rooted outside was estimated and recorded in the total percentage of cover but not included in the frequency data.

Dead shrubs and tree seedlings occurring within subplots were recorded by species. The influence of trees either rooted within or without the plot was noted. A qualitative estimate of their effect upon the subplots was made on a percentage basis. The value of one-hundred per cent was assessed if the shade, leaf deposits, moisture requirements or other influences brought about by the tree precluded the possibility of seedling establishment. Intermediate stages of influences were assessed values from one to one hundred per cent. In addition to tallying shrubs, trees and seedlings by height classes, additional height data were taken by obtaining the mean heights of the individual shrubs species over the entire macroplot.

The estimate of the amount of ground covered by herbage was constantly checked through the use of the two wire estimating rings--one covering two per cent and the other five per cent of the one-foot-by-two-foot subplot area.

Simple frequency information was automatically recorded with either the total number of plants in each subplot or the presence of species. Individual plants whose roots were located within the subplot were tallied with the frequency data even though foliage fell outside. Herbage extending into the subplot from plants rooted without it were included with the percentage of cover but were not included in the frequency information.

The pine and juniper reproduction was rarely encountered within any of the subplots and occurred within the macroplots with a fairly low frequency. In order to provide some information in addition to the systematic sampling system previously described, a thorough reconnaissance was made of the area approximately one-fourth of a mile from the center of the macroplot. It was quickly apparent that the seedlings could be found in only limited areas in which especially favorable moisture and cover prevailed. Under these conditions seedlings were frequently abundant. For this reason no overall estimate of stocking criteria such as total number of seedlings per acre or percentage stocked quadrats was made.

After completion of subplot sampling, a careful and thorough search was made of the total area within the macroplot boundaries for the species not yet recorded.

Increment cores were taken from each ponderosa pine tree falling within the macroplot. In addition, some trees immediately adjacent to boundaries of the plots were also sampled. The cores were for the purposes of determining ages and growth rates if such data later appeared pertinent.

Soil Sampling and Description

A soil pit was excavated within each macroplot. Pits were located no closer than three feet from the macroplot boundary. Concentrations of shrubs or trees were avoided as well as large rocks and other obstructions. Soil pits were excavated at least to the caliche zone which underlies all the soils at varying depths. At least one pit in each soil vegetation type was excavated through the caliche layer which was often as much as three feet in depth. This procedure was not followed where horizons did not occur. Here the soil, in so far as the plants were concerned, could be characterized almost entirely by the depth of the sand layer.

Several pits were excavated in sand, one to a depth of eleven feet. When sufficient pits had been dug in the sands to assure uniformity, samples from each macroplot were taken with the auger at one foot depth-intervals beginning with the surface. All soils horizons, whether related in a genetic sense or not, were excavated and sampled from an open pit. One exception was the lake sage area where, in a few plots, samples were obtained from the lower horizons with an auger.

A soil pit was excavated in each macroplot established during the summer of 1959. In 1960 when eighteen additional plots were established, pits were excavated in zonal soils only. Profiles were described during this latter year only in one pit of each type. The azonal sands were not described except as sands even though conspicuous vegetational differences existed. Samples were taken from each horizon in the zonal soils and at one foot intervals in the sands for laboratory analysis.

Soil Moisture Depletion

To provide an insight into the soil moisture content of the soil and of moisture depletion during the growing season, seven sampling stations were established in March, 1960, immediately after spring snow melt. One sampling station was located in each of the T-0, T-1, T-2, T-3 and T-4 types. In addition, one station was established in a dune area in the southeast end of the forest, T-6. Here, one substation was set up in a grove of pine trees and one established near by on bare sand at least fifty feet from the nearest tree. The fine sands at the southeastern sampling station are typical of most of the forest (see

Figure 31).

Another sampling station was established in one of a series of dunes with much greater mean particle size. The latter dunes are found only in a limited area on the east side and within one-half mile of the high breccia outcropping. The sands were unusual in that they were the only surface sands found in the general area of Fossil Lake and Lost Forest without a considerable mixture of pumice particles. One sampling point was located in a grove of trees and another on bare sand at least 50 feet from the nearest tree. It would have been desirable to sample farther away from living trees or other plants, but disposition of trees precluded this possibility. This was also in the T-6 vegetation type.

At the time the plots were established, water was still standing on the surface in much of the sagebrush area. Occasionally, standing water was found within some portions of the forest, particularly in the T-2 area. Most of the snow must have been melted not more than a day or two before moisture measurements were commenced. In fact, there were still a few patches of snow left in spots sheltered from both wind and sun.

Moisture samples were taken in the sand at one foot intervals down to five feet. The better developed soils were sampled by horizons. Only one sample from each level was collected for each of the sand plots since this material was very uniform. Two samples were taken from the zonal soils and these were treated as individual samples and the means of two used for moisture computation. Samples were taken with an auger wherever possible to minimize disturbances by sampling. Auger holes were refilled immediately after excavation. The individual sample sizes were approximately 800 grams. Samples were collected in paper soil bags and weighed immediately after extraction. They were later air-dried in a room with a constant temperature of 70°F and approximately forty per cent humidity. After they reached a constant weight, subsamples were extracted and the corrected moisture content obtained.

After initial sampling the sites were not resampled until June 29, 1960. At that time the soil moisture content was almost as high as when the stations were established in March. This was undoubtedly due to relatively heavy precipitation in April and May. The nearest U. S. Weather Bureau station, located at the Poplars approximately thirty miles to the southwest, recorded 2.93 inches of rainfall during April and May although none had fallen there in June. Sampling was conducted at two-week intervals through the balance of the summer until the final examination on September 26.

On June 29 a storm provided 1.12 inches of precipitation at the fine sand station. The rainfall measured at the coarse sand station was 1.02 inches. Sampling had just been completed before the storm began. In order to obtain a measure of the effect of the summer rain most of the plots were measured immediately after the rain had ceased.

Gray Rabbit Brush--Soil Moisture Relationship

The reconnaissance and the establishment of thirty macroplots during the summer of 1959 revealed that the establishment of pine seedlings nearly always occurred under or very close to gray rabbit brush plants. In some areas, particularly open sand, pine seedlings were found to be relatively abundant but never occurred except in conjunction with one of these shrubs.

To investigate this phenomenon, in June, 1960, a moisture depletion study was centered around one of these shrubs which was growing on open sand approximately sixty feet from the nearest pine tree. There were four two-to three year old ponderosa pine seedlings growing under the plant in 1959 (Figures 29, 30). One of the pine seedlings had died, however, by the time the moisture study was initiated the following year. The height of the shrub was approximately twenty inches.

It would have been desirable to study the moisture

T-0

Gray rabbit brush site.

Figure 29. Moisture depletion sites.

Figure 30. Ponderosa pine seedlings under gray rabbit brush shrubs.

relationships involved with electrical resistance type moisture measuring devices, but since these were not available, an alternate sampling plan was employed. A station from which auger samples could be taken was established directly under the shrub. Additional samples were taken at two-foot intervals along each of four transects extending eight feet outward in cardinal directions. At each point on the lines samples of approximately 250 grams were taken at the following depths; surface, six inches, twelve inches, eighteen inches, twenty-four inches and thirty-six inches. The only difficulty encountered in obtaining samples at the desired specific depth was at the six-inch level where, during the summer dry periods, the sand was loose and flowed almost as readily as water. At all other levels there was always sufficient moisture present to keep the sand firmly in place. After samples were extracted the moist sand was immediately replaced in the hole.

The samples were collected in moisture-proof soil bags and weighed immediately. They were air-dried in the sun to a constant weight (approximately one per cent) and reweighed. The weights were later corrected to oven-dry weight by means of subsamples which were dried for twenty-four hours at 110°C. This experiment was continued until August 31 when final samples were selected. On September 27 the pine seedlings under the shrub were carefully excavated to determine the characteristic root patterns.

No attempt was made to completely excavate the large root system of the rabbit brush plant utilized for the study. Several smaller shrubs were, however, carefully removed and their characteristic root distributions compared to that of larger plants. Those excavated from the azonal sands appeared quite similar. Photographs were made of these root systems rearranged into two dimensional facsimiles of their distribution patterns.

<u>Ponderosa Pine Soil Moisture Depletion Transect</u>

A study similar to the one for the rabbit brush soil moisture relationships was devised to obtain some insight into the moisture regime of the soil under the ponderosa pine trees. Two pine trees growing on sand dunes were selected as subjects for the project (Figure 31). One of these was ten inches in diameter and the other twenty inches. The former was thirty-five feet in height and the latter eighty-five feet high. A transect was initiated at the smaller tree and extended 160 feet to the larger tree thence further into a bare sand area for an additional one-hundred feet. There were no other pine trees close to the transect at any point. The sampling stations were estab-

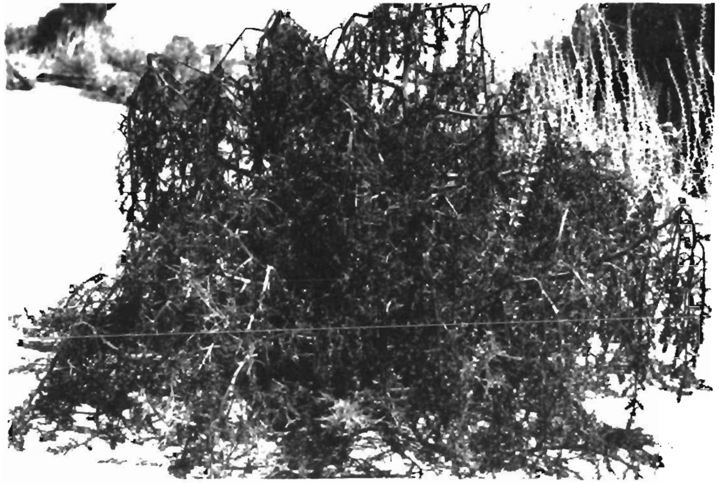
Figure 31. Ponderosa pine moisture study site. Rabbit brush excavation in foreground.

lished both directly under each of the individual treea and at twenty-foot intervals along the transects. Samples were taken at one-foot intervals beginning at one foot below the surface. In most cases samples were collected with the auger to depths of three feet. To obtain samples under the pine trees, needles and litter were removed. Samples from all transects at all sampling depths were obtained on August 31. The individual gravimetric samples were weighed on site, dried in the sun, and later corrected to oven-dry weights in the same manner as the rabbit brush soil.

Soil Permeability

It was observed that after rains, water penetrated sands very readily while in some areas of heavier soils water remained on the surface for some time after the rain had ceased. In both the T-3 upland sage and the T-4 lake sage areas the soil surface remained damp for several days. This appeared in many places as much as a week after each of the two summer rains in 1959 and 1960 respectively. In 1960 moisture still darkened the surface several days after the rain (Figure 32D). This appeared early in the morning before the heat of the sun could evaporate the moisture faster than it was conducted to the surface and continued as long as ten days after the storm. The sand dried off quickly after the rain had ceased.

A



Russian thistle killed by July frost.

B

Result of July rain.

C

Soil permeability station.

D

Moist soil ten days after rain.

Figure 32.

To measure relative penetration rates a direct method employing two six-inch by twelve-inch sheet metal cylinders was used. The bases of the cylinders were forced into the surface layer to sufficient depths to retain water which was placed in the cylinder (Figure 32C). Approximately two liters of water at 18°C were used. The drop in water level within the cylinders was recorded for two minutes and then the time noted until the cylinder had emptied or until after the expiration of a total of thirty minutes. The penetration after the duration of the first two minutes was considered as the penetration rate for the eight soils sampled. The two-minute period was the interval chosen as the time necessary to saturate the immediate surface.

It is recognized that there could be considerable loss from the periphery of the cylinder's base outward which should not be logically attributed to a direct lineal penetration rate. Since these data are only for comparative purposes and because of the great magnitude of the most of the penetration rates resulting, no correction appears warranted. Two simultaneous measurements were taken at each point sampled with the two cylinders approximately six feet apart. Eight sampling stations were chosen in representative soils from the following types:

T-0 Pine - coarse loamy sand

T-1 Pine occasional juniper - fine loamy sand

T-2 Juniper - Low sage, occasional pine

T-3 Upland sage

T-4 Lake sage

T-6 Pine - fine sand

a Bare dune sand

b Sand under pine litter

Root Patterns of Common Species

The loose azonal sand of the Lost Forest afforded an excellent opportunity to excavate and observe root patterns of several common species of shrubs and trees. Shallow sands on top of heavier soils provided an insight into the adaptability of the root system under such conditions. Two-layer root systems were quite common with one growth pattern manifest in the amorphous sand and another in soil of lower levels. The shifting sands have also uncovered surface roots of many trees and shrubs, thus providing an evaluation of root distribution. Most of the information obtained from the study of root systems was recorded photographically.

Climatic Observations 1959-1960

Ambient temperatures were recorded in the forest during the period of residence by means of a small temperature recording thermometer (Tempscribe). Precipitation was measured by means of No. 10 canning tins as described by Berry and Berg (21). An attempt was made to sample precipitation on a much more intensive basis and to determine more precisely the exact precipitation occurring in the area during the period of the study but the gauges became casualties to hunters, wild animals, domestic animals and other agencies. Other hazards encountered with this type of rain gauge were the numerous insects which were attracted to the gauges and apparently acted as wicks "siphoning" water up through the layer of oil intended for an evaporation preventative.

Surface temperatures of the soil were taken with a mercury bulb thermometer primarily to determine maxima to which seedlings are subjected. Surface temperatures were measured and recorded only during the daytime. It appeared unnecessary to employ more intensive methods since the temperatures observed in the sun on bare soil or sand from 9 a.m. to approximately 4 p.m. were invariably within one or two degrees of 59°C. This reading approximated temperature at 4 mm. below the surface. The procedure followed in making the measurements was to place the bulb of the thermometer in the soil surface so that the upper surface of the bulb was slightly below the mean sand surface and covering until it was no longer visible. No attempt was made to determine the air temperature immediately above the surface. Direct measurements were also made of soil temperature at three-foot depths in the sand by means of placing a thermometer in an auger hole until three or more identical readings were obtained. Only a few of these measurements were taken since the temperatures were invariably 14^{o} - $15^{o}C$.

In addition to surface temperature measurements and the measurements at 36-inch depths, two remote recording thermometers were employed to obtain temperatures at two-inch depths and six-inch depths. All measurements were taken below bare mineral soil surfaces.

The Tree-Ring Record

Tree ring analyses were made in the Lost Forest, near the Fremont weather station and on Hayes Butte near The Poplars station to better characterize climatical trends within the forest and to relate the Lost Forest Climate to known weather observation points.

Increment cores collected in a preliminary study showed considerable variation in relative growth rate from tree to tree. Occasional indications of missing rings were observed although it was difficult to substantiate this with but a single increment core from each tree. Accordingly refinement of techniques was initiated in an attempt to solve the problem of missing rings and false rings and to decrease variability in relative growth rates as determined from single increment cores. Trees to be used for the study were carefully selected; in the Lost Forest only those growing on sand dunes five feet or more in depth were sampled. Trees showing evidence of injury from porcupine, falling trees, insects, decay or other agencies were rejected. An attempt was made to sample trees in approximately the same age class as those with which they were to be compared. Instead of a single increment core, four were taken from each tree, one from each of the four cardinal directions.

Fourteen trees from the Lost Forest were sampled; four trees on Hayes Butte near The Poplars weather station were also sampled; and five trees were sampled within one-half mile of the Fremont weather station (Figure 25D). The trees were selected using the same criteria as for the Lost Forest except for the fact that they were not growing on sand dunes. The Hayes Butte trees were well isolated from each other, save for a forked individual, but were growing on very shallow soil. The ages of the four Hayes Butte trees were from 150-250 years.

One increment core was taken to the heart of each tree in order to obtain an approximate age. The other three cores for each tree were extended to sufficient depths to obtain at least sixty-year record.

Isolated Ponderosa Pines

In the autumn of 1960 a reconnaissance for other isolated ponderosa pines in the Northern Great Basin was made. Many of these had been reported to the author by local ranchers, foresters and range managers. In all twenty of these specimens were investigated. Photographs were taken along with notes of the location, other vegetation, pine reproduction, site and other pertinent data. A few other isolated pines were reported by reliable sources but were not visited.

Seed Collection

Cones were collected from four individual trees in widely separated portions of the Lost Forest. Approximately the same quantity of cones were gathered from each tree and well mixed. The seeds were mature when the cones were picked. The megagametophyte was firm and filled the seed coat completely.

For comparative germination studies cones were also collected from a ponderosa pine-Douglas fir-white fir site on Cache Creek at 4,400 feet in elevation in the northern portion of the Deschutes National Forest. The cones were from a large squirrel cache which was probably made from several trees. Two additional sources were supplied by the

Oregon State University Seed Testing Laboratory. These sites were not precisely known but were from United States Forest Service collections from an elevation of approximately 4,400 feet. The general location of the collections was Fremont National Forest which lies immediately south of the Northern Great Basin. The seed lots were collected in 1958 and had remained in storage at 4° to 5°C.

<u>Extraction of Pollen Bearing Sediments</u>

A deposit of silt size ash was located at about forty feet below one of the old beaches near the center of the forest. A pit was excavated and a column of the lightly cemented material was carefully removed to be examined in the laboratory later for possible pollen content. (Figure 33).

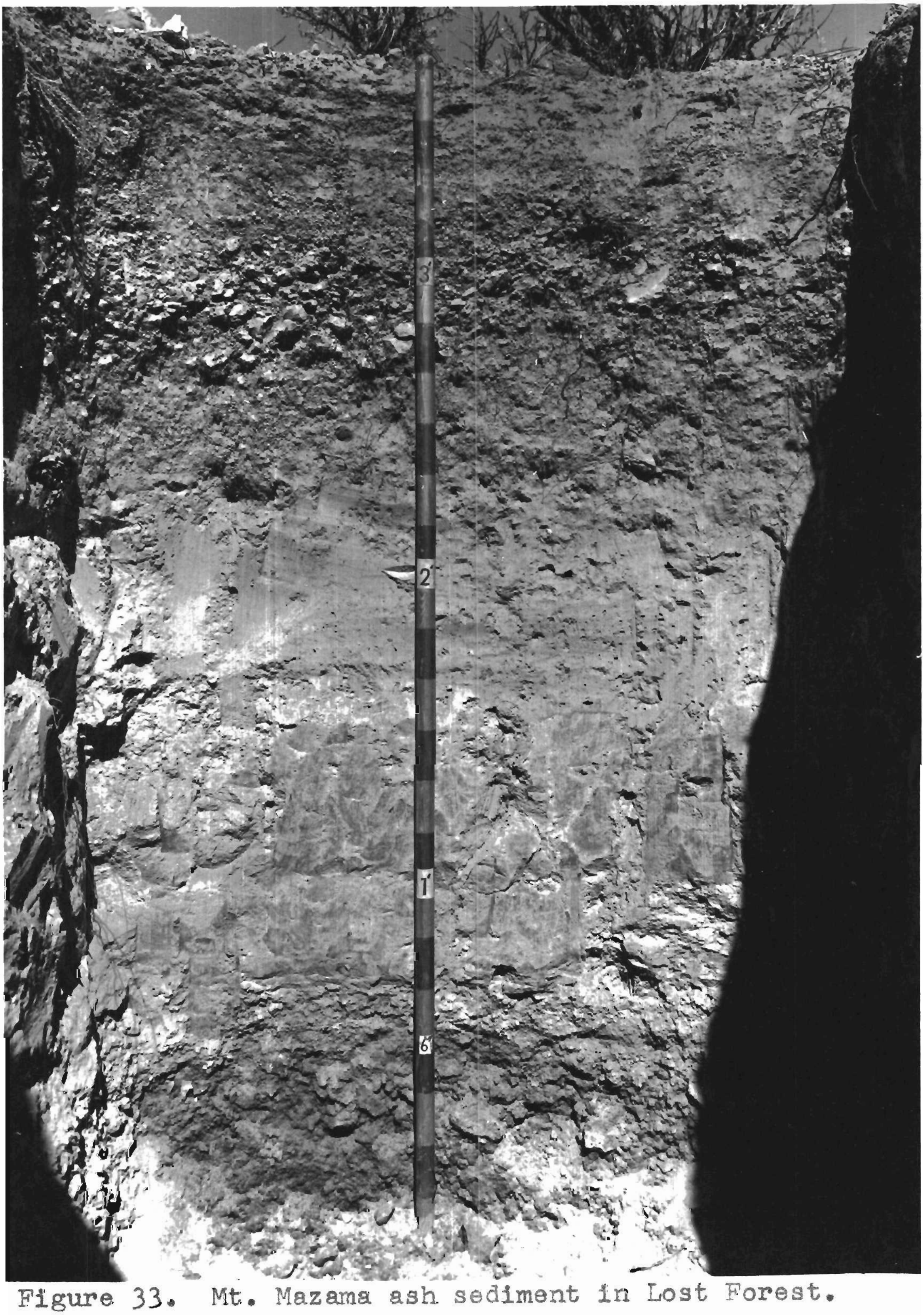


Figure 33. Mt. Mazama ash sediment in Lost Forest.

STUDY METHODS
(Laboratory)

Mechanical Analysis of Soils

Mechanical analyses of soil samples from T-0, T-1, T-2, T-3 Upland sage, T-4 Lake sage were made by the author in the soil laboratory of the Oregon State University, Soils Department. The hydrometer method was followed as described in "Sampling Procedures and Methods of Analysis for Forest Soils," (67). Several samples of sand were also included in the analysis. The sands were also sorted by screening to determine the relative proportions of various particle sizes. This was particularly important since most of the sands include considerable proportions of pumice particles of such low density that the settling rate-particle size relationship upon which the hydrometer method is based is not entirely valid.

Moisture Equivalent

Moisture equivalents were also obtained to determine an approximation of field capacity for the soils in vegetation types studied in the Lost Forest. Basically the analysis consists of subjecting a thirty-gram sample of soil which has been saturated with water to a centrifugal force 1,000 times gravity for thirty minutes (67). For medium textured soils this is a good laboratory approximation of field capacity (18). Since many of the sands were found through gravimetric methods to contain more than the field capacity which their moisture equivalents indicated, the samples were also subjected to a pressure table test at .1 atmosphere. The latter were conducted by the testing service of Oregon State University Soils Department.

Chemical Analysis of Soils

Laboratory chemical analyses were performed by the soil testing laboratory of Oregon State University Soils Department. The test included determination of total organic matter, nitrogen percentage, soil reaction (pH), cation exchange capacity, available phosphorous, exchangeable potassium, sodium, calcium, and total salts and exchangeable magnesium.

Determination of Seed Germination Characteristics

Since ponderosa pine seeds from different seed lots commonly show considerable variation in their germination requirements and their response to standard germination treatments, seeds from the Lost Forest were compared with seeds from three other sources for possible variations in behavior.

The tests appeared particularly desirable in light of two specific environmental circumstances. The upper six-inch zone of the sands where most of the pine seedlings are found dries out within a few hours after saturation. The other circumstance is the limited time during which both temperature and soil moisture are adequate to produce seed germination. Thus a physiological mechanism adaptive to this condition appeared to be a possibility.

The Lost Forest and Cache Creek wet site cones were dried at 20°C with the humidity at approximately forty per cent for three months. Wings were removed by hand rubbing to prevent mechanical damage. Seeds were stored until the following spring at room temperature and then placed in tinned containers and stored at 5°C until germination tests were begun in November, 1960.

<u>Standard Germination Test</u> In the initial test the seeds were all treated prior to a germination test; the treatment consisted of soaking in tap water for thirty-six hours at 4°C, followed by stratification at 4 to 5°C, on saturated paper toweling for six weeks. Final germination tests consisted of placing one-hundred seeds from each lot on a

substrate of "Spongerock" (Pearlite) in a covered petri dish. The containers were placed in a germinating oven in which alternating 20°C to 30°C temperatures were maintained for six-hour and eighteen-hour periods respectively. The 30°C temperatures were accompanied by light while during the 20°C period, the oven remained dark. The progress of germination was recorded beginning at four days. Germination was considered complete at the end of the tenth day. For both the Cache Creek and the Lost Forest sources this preliminary germination test, which was conducted primarily for the purpose of determining total germination, also indicated the possibility of a superior germinative energy in the Lost Forest seed. For example, on the fourth day the mean germination percentage for the Lost Forest seeds was approximately ninety per cent while the next best source showed but sixty-three per cent. One source showed but fifty-one per cent during the same period.

Experimental Germination

For the purpose of securing more precise information as to possible superior germinative energy of the Lost Forest seeds, the standard laboratory procedures were abandoned and an experimental test designed. The experiment was planned to compare germinative energy among the four sources over three pre-treatments. The three pre-treatments. The three pre-treatments were as follows: (a) Soaking for thirty-six hours at 4°C followed by six weeks naked stratification at the same temperature; (b) Soaking in tap water for twenty-four hours at 4°C; (c) Dry, no pre-treatment, (seeds were taken immediately from storage at 5°C and placed on the substrate).

For each treatment 125 seeds were used. These were placed twenty-five in each covered petri dish, thus providing five replications. The conditions of the light were the same as for the standard test; that is six hours light followed by eighteen hours dark with the dark periods corresponding to low temperatures and light periods to high temperatures. Instead of the alternating 20°C, 30°C maintained for ideal germinating conditions, a low temperature of 5°C and a high of 15°C were maintained during the tests.

The first observations were made on the fourth day on which none of the seeds had germinated. The germinants were counted daily from the fifth day for seven days then at two-day intervals for six days, and at three-and-four-day intervals until the experiment was completed after 21 days. The criterion employed in determining germination of individual seeds was emergence of the cotyledon to the point where individual leaves had commenced to separate. All abnormal germinating seeds were counted among total germinable seeds, but not as germinants regardless of extent of growth. Percentage of germination for each period was determined on the basis of sound seeds.

Seedling Drought Resistance Study

One of the theoretical mechanisms through which the trees in the Lost Forest could survive is a adaptation to the xeric conditions. If such a mechanism were responsible it is most probable it would become manifest in the seedlings since the ability of ponderosa pine to maintain itself under arid conditions appears to be limited by the establishment and survival of its seedlings rather than the maintenance of growth and development of mature trees. It was recognized that the possibilities of discovering a physiologically drought resistant seedling were rather remote.

An experiment was designed to compare the drought resistance of seedlings from the Lost Forest and three other sources. The seed lots used were the same as those described in "Determination of Seed Germination Characteristics." This provided one wet site and two dry site seed sources in addition to the Lost Forest. After six weeks of stratification the seeds were germinated in an experimental seed germinating oven by alternating 20°C and 30°C temperatures. A dark period was provided to correspond with the low temperature and the light period with the higher temperature. The cycle was on a six-hour-eighteen hour basis. As soon as the cotyledon had emerged from sufficient numbers of the seeds the germinated seedling was planted. The substrate used for the experiment was the fine sand collected from the Lost Forest. Six germinated seeds were planted in each pot. The pots were of approximately one pint in capacity. Thirty pots were employed for each seed lot. Planting was completed on November 21 and 22, 1960 and pots were immediately placed in a chamber in which the temperature was maintained at 78°F for daytime periods and 48°F for nighttime periods. An artificial sixteen-hour light period was related to the temperature cycle with the dark portion of the cycle concurrent with the lower temperature.

The plants were irrigated twice weekly with tap water. Sufficient water was added each time to saturate the soil, excess moisture drained from the pots immediately after irrigation so that there was no aeration problem. No nutrients were added either to the water or to the soil. Survival of the seedlings was excellent in all 120 pots; none had less than five healthy seedlings. All six seedlings survived in all but seven pots. The 120 pots were arranged within the growth chamber in rows in such a way that no two adjacent rows contained seedlings of the same origin (Figure 34).

On January 5, after approximately six weeks, three sunflower seeds were placed in each pot. After one month the sunflower plants had reached the height of approximately fourteen inches. At this time irrigation was terminated. Thirteen days later in approximately two-thirds of the pots, sunflowers showed evidence of wilting i.e. flaccid cotyledons and were detopped. Two days later, the soil moisture in the balance of the pots had reached the wilting point. Thereafter the pots were observed daily for evidence of dying pine seedlings. The first seedling to show evidence of moisture deficiency was noted thirteen days after the soil had reached the wilting point.

Drought resistance was evaluated in terms of the mean number of days which the seedlings were able to survive after the wilting point of the sunflowers was reached. Seedling death criteria were the wilting of needles or the development of necrotic spots without the outward manifestations of wilting. The cotyledons had died before or at about the time irrigation was terminated so that they could not be used as indicators. The usual pattern was a visible wilting of all or most of the leaves with some reddish discoloring; or most of the leaves with some reddish discoloring; or most of the leaves wilted with a few necrotic spots on the remainder. As a check on the

Wilting sunflowers.

Pots immediately after removal of sunflowers.

Figure 34. Ponderosa pine seedling drought study.

criteria, pots were rewatered as quickly as the last seedling was classified as dead. A few such seedlings put out some new leaves but none fully recovered. A few pots in which part of the seedlings had died were rewatered. In several such cases the balance of the seedlings continued to grow. This indicated that the criteria were reasonably accurate.

After termination of the experiment the plants were excavated and oven dry weights of seedlings were determined. The pine seedling roots had grown together in such an interwoven mat that it was impossible to separate them into individuals. Most of the sunflower roots were removed, but a small residue impossible to extract was weighed with the pine root systems. The sunflower roots were very fine and of such low density that they probably did not bias the results. Root top ratios for the plants were also determined.

Identification of Pumice and Pollen Extraction

The material was first examined with the aid of a petrographic microscope to determine the nature of the minerals contained. This was for the purpose of identifying it with one of the known ash falls if possible.

Techniques for extracting pollen, since quantitative analysis was not planned, were somewhat gross. Samples taken at one-inch intervals from the 38-inch level to the 22-inch level were soaked for twenty-four hours in hydrofluoric acid, covered with H_2O, decanted until a neutral reaction was obtained. Samples were then placed in Schulze's solution (one part saturated potassium chlorate solution and two parts concentrated nitric acid). They were digested in a fume hood with occasional stirring for twelve to sixteen hours. The washing procedure was repeated again until a neutral reaction was obtained and samples soaked in a ten per cent solution of KOH for approximately one hour. They were again washed with water until a neutral reaction was obtained. Between washings, heavy solids were settled by centrifuging. After completion of the above steps each of the samples was placed in a test tube and the heavy solids permitted to settle for approximately one minute. The remainder was decanted and centrifuged again to secure the remaining solids; the water was poured out and the residue dried with ninety-five per cent alcohol. The material was stained with safranine and deposited on slides. One drop of diaphane was added to each slide and a cover slip affixed. The slides were examined for pollen under a magnification of approximately 440X.

The Tree Ring Record

Annual growth rings were measured for radial increment with a microscope and a micrometer stage developed for the purpose by the United States Forest Service.

Annual rings produced by the slower growing trees and those produced during periods of low precipitation often proved extremely difficult to identify even with forty-diameter enlargement. A number of stains were tried and the most effective was as follows: 0.03 gm. malachite green, 0.03 gm. methylene blue, 50 cc. 95% ethanol. Even with this stain considerable care was necessary to detect the annual growth pattern.

The following procedure appeared to give the best results. Before staining, the cores were soaked for at least eight hours in tap water, then sliced with a sharp razor blade while still wet so that a transverse view of the tracheids was obtained. The excess water was wiped off with a clean cloth or sponge and the stain applied with a camel hair brush while the core was still damp. The first application usually provided uneven staining so that a second application was necessary to produce uniform results. Cores could be analyzed under the microscope as soon as the stain and the excess water disappeared from the surface. The best results were obtained, however, after the cores had been permitted to dry for at least three hours and then remoistened with a damp sponge. The latter treatment frequently brought out annual growth rings which failed to appear under any other circumstances.

The specially designed micrometer stage employed could be read to 0.02 mm. The smallest growth ring identified was .04 mm. The four cores from each tree were matched for missing or false rings after a preliminary measurement. In only two cases were false rings definitely detected. In nearly every tree, however, at least one ring was missed in the first measurement. In all these cases, agreement was obtained from among the remaining three cores and when the area of the presumed missing ring was re-examined it could be brought out by restaining and remoistening as previously described. In some cases the "missing ring" stood out only when the core was dry.

In many trees the variation among the four cores from one individual appeared to be as high as might be expected of four cores from four separate trees. After the cores were matched to the point where agreement was obtained for salient points (representing extreme departures in precipitation) the mean radial growth for each year was calculated for each year for each tree. A standard measure of annual increment was obtained by weighting the mean radial growth of each tree by the reciprocal of that individual's standard deviation. This latter procedure has considerable advantage over expression of growth in terms of percentage of the mean for the period as used by Keen (106) and Antevs (9). It emphasizes the fluctuations of the growth of those trees showing more uniform increment and at the same time reduces the extreme responses of the more variable individuals. To provide a simple comparison of growth responses among the Lost Forest, The Poplars, and Fremont groups of trees the mean of standard measures were obtained for each year within each group (121) (140). The data were then plotted on a graph with standard measure on the vertical axis and time on the horizontal axis.

The three localities were compared for long range agreement and for salient points. They were also compared with the tree growth records of Antevs (9), Keen (106). They were also plotted with Cliff precipitation records. Annual precipitation proved difficult to follow when plotted directly on the same chart with the standard measure of tree growth. In order to provide a legible graph and to make allowance for the delay in response of trees to changes in precipitation levels, each annual precipitation value was replaced by the mean of that year's and the two previous years' precipitation.