PURPOSE OF STUDY

The study was undertaken with the dual purpose of determining the nature of the community or communities constituting the forest and determining how it was able to survive under conditions which normally do not permit the growth of ponderosa pine. To implement the more general purpose, eight more specific objectives were defined. It was expected that probably not all of these could be accomplished--at least not to the fullest degree. However, it was felt that a meaningful appraisal of the situation could not be attained without pursuing these objectives.

The objectives were as follows:

1. To characterize the vegetation of the Lost Forest and adjacent area.
2. To characterize and compare the soils of the Lost Forest and the adjacent area and to relate them to vegetation types, where possible.
3. To determine the natural stability of the present stand and ascertain whether it is increasing or decreasing.
4. To characterize climatic factors in the Lost Forest.

5. To determine the means by which ponderosa pine trees exist under the present conditions of low precipitation.
6. To determine reason(s) for differences in vegetation within the forest and between the forest and the adjacent area.
7. To determine the origin of stand if possible.
8. To determine the impact of past and present land use on the forest and immediate vicinity.

REVIEW OF THE LITERATURE

Soil-vegetation Relationships

No soil-vegetation studies have been completed in the Sierozem Soil Zone concerned in this study. Eckert (60) however, conducted a soil-vegetation study in the Brown Soil area of Northern Lake and Harney Counties. He succeeded in defining four separate communities. These were (1) *Artemisia tridentata* - *Agropyron spicatum*; (2) *Artemisia tridentata var. arbuscula* - *Festuca idahoensis* and (4) *Artemisia tridentata var. arbuscula* - *Agropyron spicatum*. In addition to the typical *Artemisia tridentata* - *Agropyron spicatum* community, a *Stipa* phase was also recognized.

Eckert also conducted moisture depletion studies in the soils related to each of his plant communities and from these he concluded that soil moisture depletion was the key to vegetation associations.

Dyrness (59) conducted a soil-vegetation relationship study in the ponderosa pine type fifty miles southwest of the Lost Forest. Soils in the area studied by Dyrness are dissimilar from those in the Lost Forest area in that they are derived from an aeolian parent material consisting mostly of pumice sand and gravel from Mt. Mazama. The precipitation of the area is approximately twenty inches or slightly more than twice that of the Lost Forest. The area studied by Dyrness is also characterized by a much greater number of plant species, as would be expected in the more mesic environment.

Dyrness (59) was able to define six interpretive vegetation units which he listed in order of increasing effective moisture as follows:

(1) *Pinus ponderosa* - (*Purshia tridentata*)

(2) *Pinus ponderosa* - (*Purshia tridentata Festuca idahoensis*)

(3) *Pinus ponderosa* - (*Purshia tridentata*, *Arctostaphylos parryana var. pineforum* (Rollins) Wies. & Schr.)

(4) *Pinus ponderosa* (*Ceanothus velutinus* Dougl. - *Purshia tridentata*)

(5) *Pinus ponderosa* (*Ceanothus velutinus*)

(6) *Abies concolor* Lindl. (*Ceanothus velutinus*)

The elevations in the study area were from 5,000 to 6,300 feet above sea level.

Autecology of Shrubs and Trees

The autecology of many of the common species found in the Lost Forest area is incompletely known. Since it is desirable, however, to know as much as possible of the nutrient requirements, physiology, climatic responses, morphology and other characteristics of as many associated species as possible, the literature concerning the following species is reviewed. Photographs accompanying the literature review were taken in the Lost Forest.

Bitter Brush (*Purshia tridentata*) - Bitter brush grows throughout the arid sections of eastern Oregon, Washington, the Rocky Mountains and in California. It is a rigid, copiously branched shrub with small, narrow leaves. It may reach heights of as much as twelve to fifteen feet but normally grows as a shrub of three or four feet in height. At elevations of 4,000 feet, flowering normally occurs in May and early June. In the Lost Forest it flowers in May with seeds maturing in early July. Leaves appear at these altitudes in April.

Stanton (147) found that bitter brush plants from eleven to fifteen years of age were overtopping sagebrush of any age and that mean heights more than doubled in the next five years after this occurred. Bitter brush apparently finds its optimum habitat on cutover ponderosa pine sites in central Oregon. Most of the soils in this region are of pumice origin. Stanton (147) indicates that bitter brush growth is considerably more rapid than that of sagebrush. He gave mean heights of eighteen inches for sagebrush at eighteen to twenty years and twenty-seven inches for bitter brush at the end of approximately the same period. Seedlings average six to eight inches in height at the end of one year and are three feet high in three years. Crown-diameter growth of bitter brush in sagebrush sites far exceeded that in either ponderosa pine sites or lodgepole pine sites.

Young bitter brush seedlings no more than two or three inches tall have roots that penetrate the soil fifteen to twenty inches or more (Figure 17). Bitter brush seedlings, like those of rabbit brush and big sagebrush, rapidly produce long taproots (119). Bitter brush rarely sprouts but may reproduce by layering of the lower branches. As in most plants resistance of the species to adverse or extreme conditions varies with its age. Young seedlings have much less resistance than older plants. The plant is very easily destroyed by fire. Rabbit brush appears to invade burned over areas much more rapidly than bitter brush and, therefore, fire may favor the development of rabbit brush over bitter brush.

Bitter brush is susceptible to attacks by tent cater-

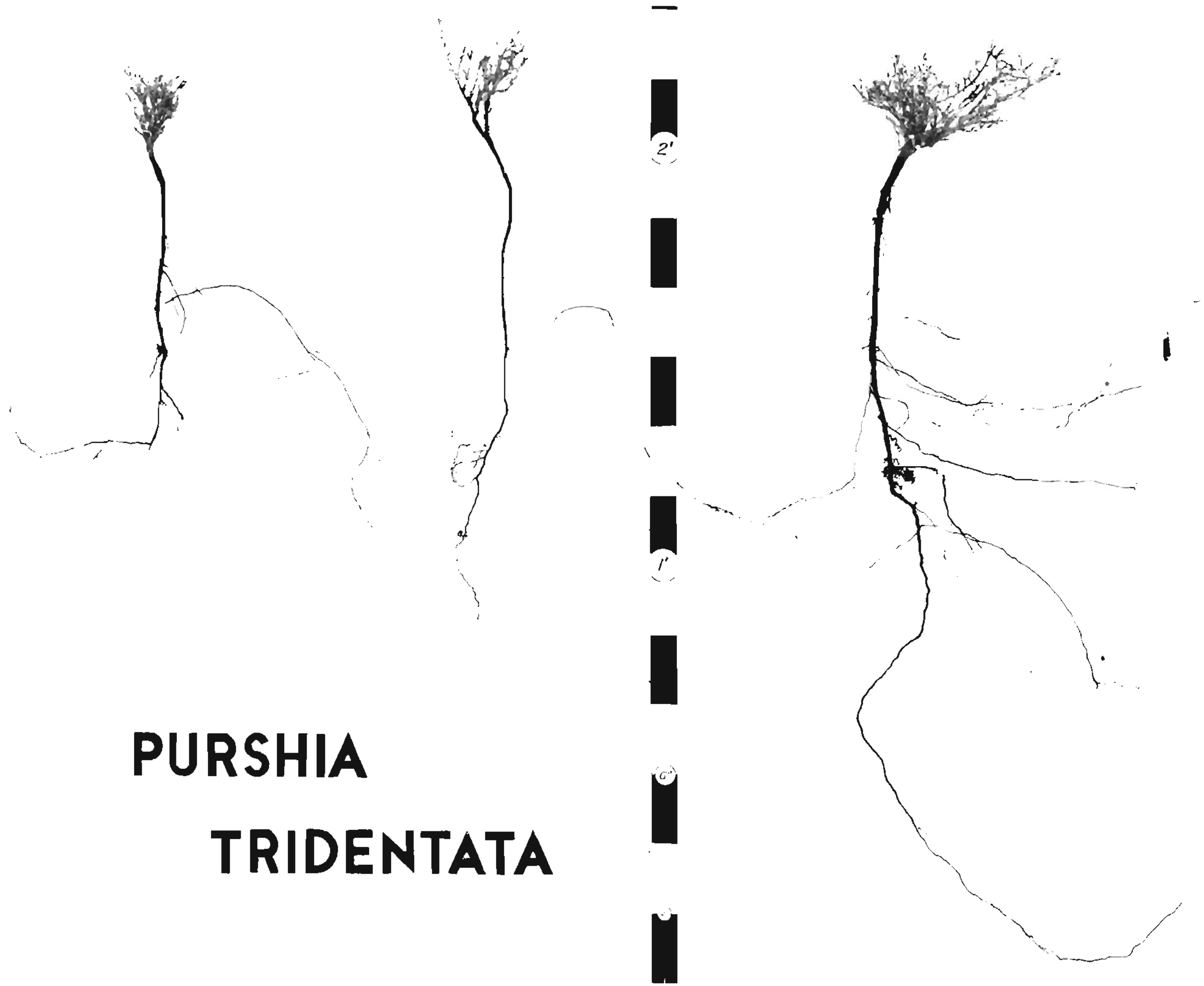


Figure 17. Bitter brush seedlings.

pillars (*Malacosoma fragilis* Stretch). It is also susceptible to other insects causing damage to shrubs, but tent caterpillars are the most serious. Light browsing causes the plants to produce less foliage but may also cause them to grow taller under such circumstances. Clipping as much as seventy-five per cent or more of the twigs practically stops height growth. Moderate clipping suppresses flower growth, thus reducing seed production.

Forsling and Storm, as cited by Stanton (147) concluded that close utilization could eventually eliminate bitter brush.

Hormay, as cited by Stanton (147), indicates that the life span of bitter brush is probably between sixty and seventy years. It begins seed production at the fourth or fifth year. The most conspicuous mode of seed distribution is by rodents. Rodents take the ripened seeds and hide them in the ground. Consequently, seedlings from the cached seeds always appear in clusters. Stanton (147) states that chipmunks and goldenmantled ground squirrels are principally responsible.

The seeds are viable for a number of years. Seeds germinated at low temperatures (33° to 38°F) have optimum germination when planted in depths of from 1 to 1.5 inches (119). Bitter brush seed requires cold treatment before germination is possible. Stanton (147) reports that the rapidly elongated taproot may penetrate from 3.0 to 3.5 feet of light textured soil in three months following emergence.

The seedlings are relatively resistant to heat damage. Stanton subjected two-week old seedlings to 150°F for one hour. The plants survived in apparently good condition and were still alive two months later.

Rabbit Brush (Chrysothamnus sp.) - Peck (132) lists two species of rabbit brush; these are gray rabbit brush (*C. nauseosus*) and sticky-flowered or green rabbit brush (*C. viscidiflorus*). He also recognizes four varieties of gray rabbit brush and four varieties of sticky-flowered rabbit brush. Individual characteristics of each of the varieties of the two species were readily identifiable in the field. However, intergrading of varietal characteristics from plant to plant was common in the Lost Forest. For this reason only the species have been recognized in the analysis of vegetation.

Both *Chrysothamnus*, (*C. nauseosus*) and (*C. viscidiflorus*), are low shrubs with conspicuous golden yellow flowers which are produced in late summer and early autumn. Gray rabbit brush grows as a low shrub; the average height is from twelve to thirty inches. Green rabbit brush is also a low shrub but rarely exceeds twenty-four inches in height and more commonly occurs from twelve to eighteen

Figure 18. Gray rabbit brush invading site left by dead ponderosa pine.

inches. Without competition gray rabbit brush may reach thirty-six to thirty-eight inches in height and thirty-six to forty-eight inches in crown diameter of from ten to eight feet. McKell (119) also noted plants near Fort Rock nearly this large. C. nauseosus may reach fifty years of age while C. viscidiflorus rarely exceeds twenty-three years (119).

Both species are found in arid regions throughout the Great Basin area from the lowest elevations to the higher points (119). It is also found throughout most of the other arid regions of the west. Sagebrush also appears to reduce their flowering frequency. This is particularly true of C. viscidiflorus.

Seeds of both species are wind disseminated, and the range of dissemination by this means is from four-hundred to five-hundred feet (119). This is much higher than for sagebrush and may partially account for the rapid ascendance of rabbit brush when sage is disturbed.

Seeds may germinate immediately upon maturity at (119) temperatures from 5 to 30°C. This may also be a factor in the invasion of rabbit brush into sage communities. In experiments conducted by McKell (119), rabbit brush seedlings were resistant to temperatures as low as -5°C when germinated at +5°C. Those germinated at higher temperatures were unable to survive freezing. Seedling survival appears

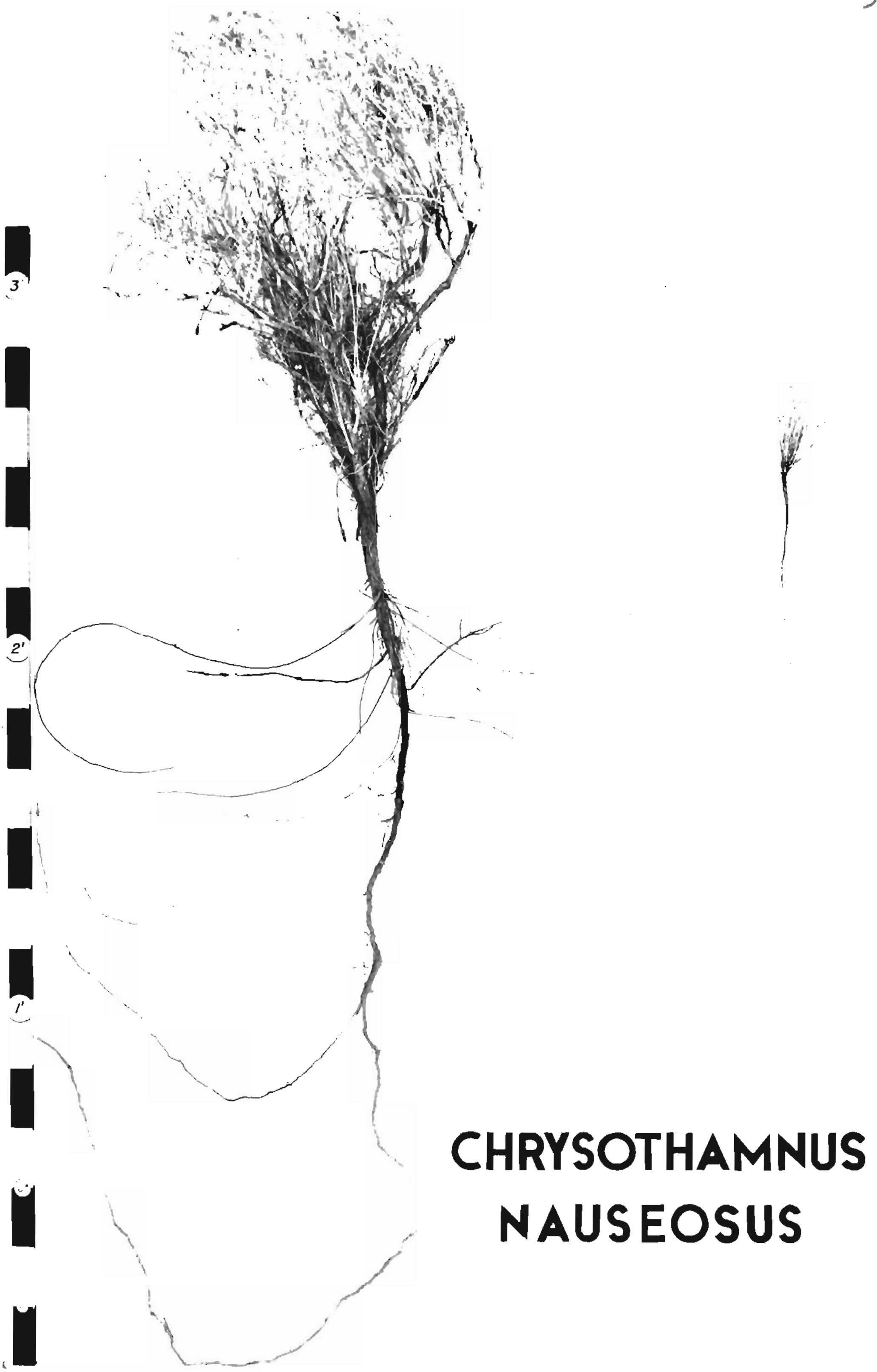


Figure 19. Gray rabbit brush root system.

best on the loamy-sand soils when seeds are planted at depths of from 1/4 to 1/8 inches. Four-week old seedlings were able to survive temperatures of approximately 140°F as long as the roots were in moist soil. According to McKell drought resistance appears to develop early in the seedling stage. A higher percentage of C. viscidiflorus seedlings survive extreme drought than those of C. nauseosus seedlings. C. viscidiflorus seedlings were able to endure lower soil moisture percentage than either C. nauseosus or Artemisia tridentata.

C. nauseosus also has the ability to sprout copiously from the crown after fire or mechanical damage (119). It appears also to be remarkably resistant to damage from insects and grazing.

The root growth rate of C. viscidiflorus seedlings is greater than that of C. nauseosus (119). Root growth rates of big sage seedlings is intermediate between the two.

Flowering and seed production are relatively high for both species (119). In the Northern Great Basin area C. nauseosus plants growing with heavy stands of bunch grass produce many less flowers than normal.

Both species commence leaf development in April and May; initial flower buds occur in July and June; mature flowers in September and October. Seeds are disseminated from September and through November. Flowers mature at intervals on individual plants so that seeds are being disseminated over a considerable period of time (119).

Big Sage (Artemisia tridentata) - Big sage is an erect or ascending shrub from 1.5 feet to 16.0 feet in height (69). It is often arborescent in habit but usually has abundant branches. It most often grows in fairly dense stands of from three to five feet in height but may form dense stands much taller. Individual plants may have crowns six to eight feet in diameter but three to four feet is much more common. It appears to occupy almost any arid sites from a few hundred feet in elevation to close to the timber line. It is commonly associated with rabbit brush and bunch grass (Agropyron sp.). It appears to transcend all soil types as well as altitudinal ranges although on some of the more alkaline drylake beds, it is replaced by A. cana and in others by its diminutive form A. tridentata var. arbuscula.

Sagebrush is fairly resistant to most damaging agencies but is readily destroyed by fire where it grows in dense stands. Moomaw (124) states that it has a tendency to increase with grazing. Goodwin (69) reports that the root systems of Artemisia tridentata seedlings are able to continue growing even though the air temperature is below freezing but aerial growth of seedlings proceeds only with high temperature. This also corresponds with occurrence of twig growth on mature plants. Two sets of foliage

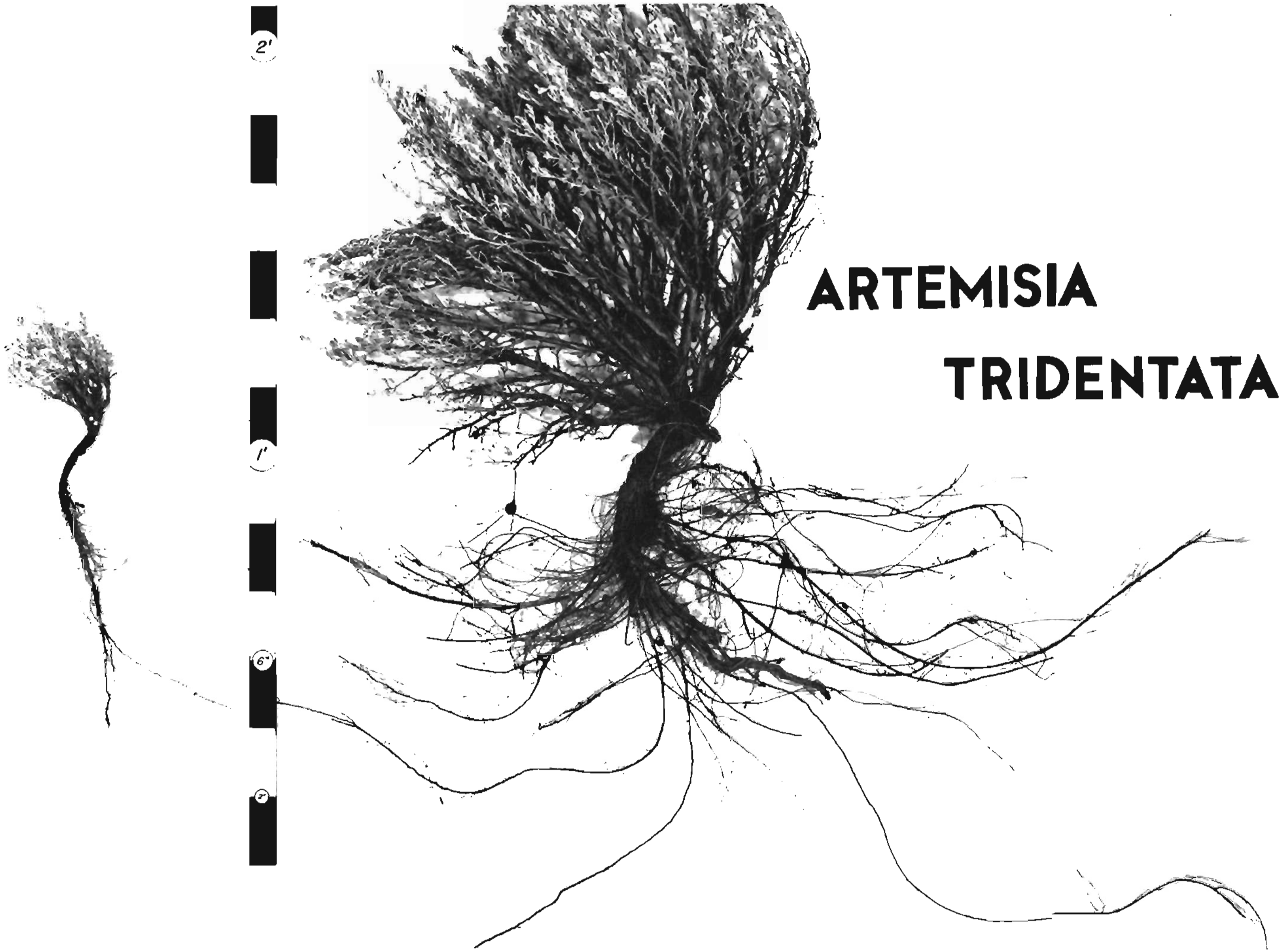


Figure 20. Big sagebrush root system.

produced during the growing season overlap and give the shrub the appearance of an evergreen.

The root system of the shrub is varying in its pattern of development. It may have a deep taproot or a shallow layer of fibrous roots. A fibrous root system distributed over a wide area approximately six inches below the surface utilizes surface moisture immediately after each rain before it quickly subsides to lower levels. The taproot extracts moisture from the more dependable sources at greater depths. Production of the lateral root system begins at about four months.

Ponderosa Pine (Pinus ponderosa) - Ponderosa pine is a large pine up to 70 meters high with diameters as much as 2.5 meters (Peck, 132). It often reaches ages of 300 to 500 years. Keen (106) found one in south central Oregon to be 668 years old. One has been recorded at 726 years. The species geographical range is from southern British Columbia into Mexico and as far east as Nebraska. Its western limit is the coast ranges of Oregon, Washington and California. It grows from sea level to altitudes of 9,000 feet although its upper limits in Oregon are much lower. Optimum development of stands in the Great Basin is at four to five thousand feet.

Curtis and Lynch (44) and Isaac (101) give its minimum precipitation requirements as about ten inches.

Average annual temperatures of its range are between 41.8 and 49.8°F. With good drainage the trees may grow under conditions of extremely heavy rainfall. In north central California the species is found growing in stands where the precipitation is as high as 69 inches. Meyer (122) states that ponderosa pine reaches its best development on well drained, deep sandy, gravel or clay loams.

Munger (126) has stated that ponderosa pines are absent where an impervious substratum exists. Holltby, Pearson and Tarrant as cited by Curtis and Lynch (44) state that texture of the soil is probably much more important in the tree's development than its chemical constituents.

Ponderosa pine seedlings grow slowly up to twenty years. The average height of ponderosa pine in a site of medium quality at twenty-years is only approximately twenty feet, on poorer sites not much over ten feet. After a period of slow seedling development, growth may be very rapid even on the poor sites.

Ponderosa pine is a fairly prolific seeder but seeds are subject to damage in the cone by a variety of insects. After dissemination seeds are sought as food by many birds and mammals. The most common and probably the most destructive of the latter is the deer mouse or white footed mouse.

Seeds are distributed by the wind. Very few seeds are

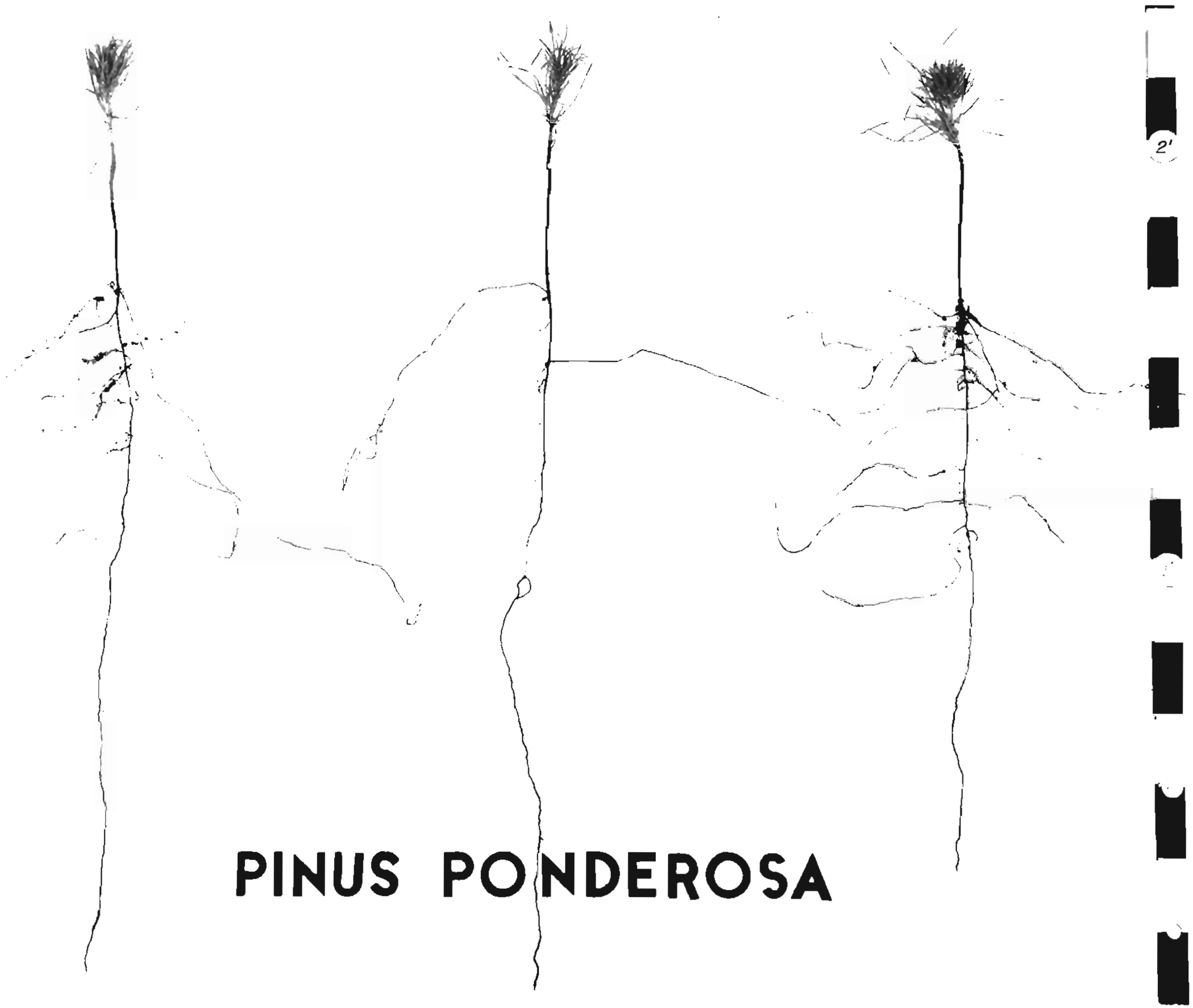


Figure 21. Two to three year old ponderosa pine seedlings grown under a gray rabbit brush plant.

carried over one hundred feet beyond the edge of timber. Ponderosa pine seedlings appear remarkably resistant to most destructive agents when they are tested under artificial conditions. The survival of seedlings in the forest is extremely low. They are subject to destruction by cut worms, birds, rodents, damping-off fungi, heat, drought, cold and other damaging agencies.

One-hundred-and-ten-day old seedlings can withstand instantaneous temperatures of 136 to 180°F (44). Some seedlings are able to survive in regions where soil temperature reaches as high as 162°F (114).

Ponderosa pine is an extravagant user of moisture when it is readily available, but its ability to send down a fast growing taproot enables it to survive on and dominate difficult sites where competition is not high (17). Roots of one-year-old natural seedlings have been known to reach average lengths of 22.4 inches with an average top height of only 2.8 inches (Figure 21). As a seedling it also possesses the ability to withstand prolonged periods of high soil moisture stress (68).

Four-year old seedling roots can average as much as five feet in length. Seedlings require full light for maximum development. They will, nevertheless, withstand overstory shade and root competition for as much as forty years.

Trees produce flowers and seed as early as sixteen years but produce most heavily from sixty to one-hundred years in age. Seeds are distributed from the latter part of August through November. Germination rate of seed is relatively high with ninety to ninety-five per cent germination under favorable conditions. Under field conditions germination is considerably less. All trees do not bear each year but no periodicity has been detected. Flowering occurs from May through June with cones and seeds maturing a little over one year subsequent to pollinization.

Fowells (68) reports that on the western slopes of the Sierra Nevada the height growth of ponderosa pine started significantly later with each 2,000-foot rise in elevation and likewise radial growth started later with each increment in elevation.

From the sapling stage to maturity ponderosa pine is subject to attack by many insects (44). The most common are the western pine beetle, Dendroctonus brevicomis Lec., and the mountain pine beetle D. monticolae Hopk. The red turpentine beetle D. valens Lec. also frequently attacks ponderosa pine but in most cases is only a secondary insect. Ponderosa pines are also subject to defoliation by insects. Most common of these are the pine butterfly Neophasia menapia Feld, the pandora moth Coloradia pandora Blake, and sawflies Neodiptrion spp.

The trees are also attacked by rootrot and buttrot, Fomes annosus (Fres) Karst. Needle blight (Elytroderma deformans) (Weir) Darker, and other fungi may attack foliage. The tree also supports dwarf mistletoe (Arceuthobium campylopodum forma campylopodum) (Englem) Gill. Normally these parasites are found associated with ponderosa pine wherever it grows in eastern Oregon. Ponderosa pine trees are also seriously damaged by the porcupine (Erethizon dorsatum epixanthum.

Young trees are damaged by fire; the thick barked older stems are very resistant. The tree is also resistant to windthrow probably because of its rather massive and deeply penetrating root system. The roots often extend outward as far as 150 feet particularly in loose soils.

Each season's growth of ponderosa pine leaves remain on the trees for about three years.

Pearson (128) states that, in Arizona, one of the limiting factors for distribution of ponderosa pine is temperature, particularly temperatures adequate for germination during June and early July. He found that seedlings grown in half shade without outside root competition survived well but after five years became so extremely slender that they were unable to bear their own weight. In twenty-five per cent shade they were able to maintain normal development. Eighty-five per cent shade produces almost total mortality within two years. Pearson states that ponderosa pine is not exacting in regard to soil. Isaac (101) reports that ponderosa pine does best on a soil with a pH value of 6.0 to 7.0 but survives at pH values from 5.0 to 9.0.

Western Juniper (*Juniperus occidentalis*) - Peck (132) describes Western juniper (*Juniperus occidentalis*) as a tree which commonly reaches up to 20 meters in height and with a trunk diameter up to 1.5 meters. It has a broad flattened crown with relatively dense foliage.

Western juniper is distributed throughout the arid areas of eastern Oregon, Washington and California. It appears to grow at almost any elevation except the high peaks. It is most commonly found on rocky ridges. Unlike *J. scopolorum* Sarg. it is not often found on highly calcareous soil. In fact, Eckert (60) found that the soil under *J. occidentalis* is 1.0 pH unit more acid in reaction than the soil of the adjacent area. Eckert has assumed that this is an effect rather than a cause of the junipers' presence.

Western juniper is dioecious with the fruits requiring two years to mature. They may commence bearing at twenty-five to thirty years of age. The fruits are fleshy and are eaten by birds. Long distance distribution of seeds is most commonly effected through the droppings of birds and some mammals. Junipers may be prolific producers of seeds at certain times but during some years the fruits are noticeably absent. Seeds ripen in the autumn but may remain on the tree through most of the winter. Pollen is produced in late March.

Resistance of western juniper to biotic agents except trunk rot is high. It is rather easily destroyed by fire. Trunks of trees partially destroyed by trunk rot are easily ignited and burn readily until the trunk is completely severed. Herman (90) states that the western juniper moisture requirements are less than those of *J. scopulorum*. The roots of western juniper seedlings are fibrous and begin to extend to considerable horizontal distances even at an early age (Figure 22). Eckert (60), states that juniper roots were considerably deeper than those of other (non-arborescent) plants.

Present Climate

Precipitation - The climate of the portion of the Northern Great Basin in Oregon is that of the Cold Desert or Steppe (93). The Lost Forest area is subject to no major changes in topography which might greatly alter its local climate. This is particularly true of precipitation when considered in periods of a year or longer. It is too far away from the high peaks of the Cascades and the other lower peaks

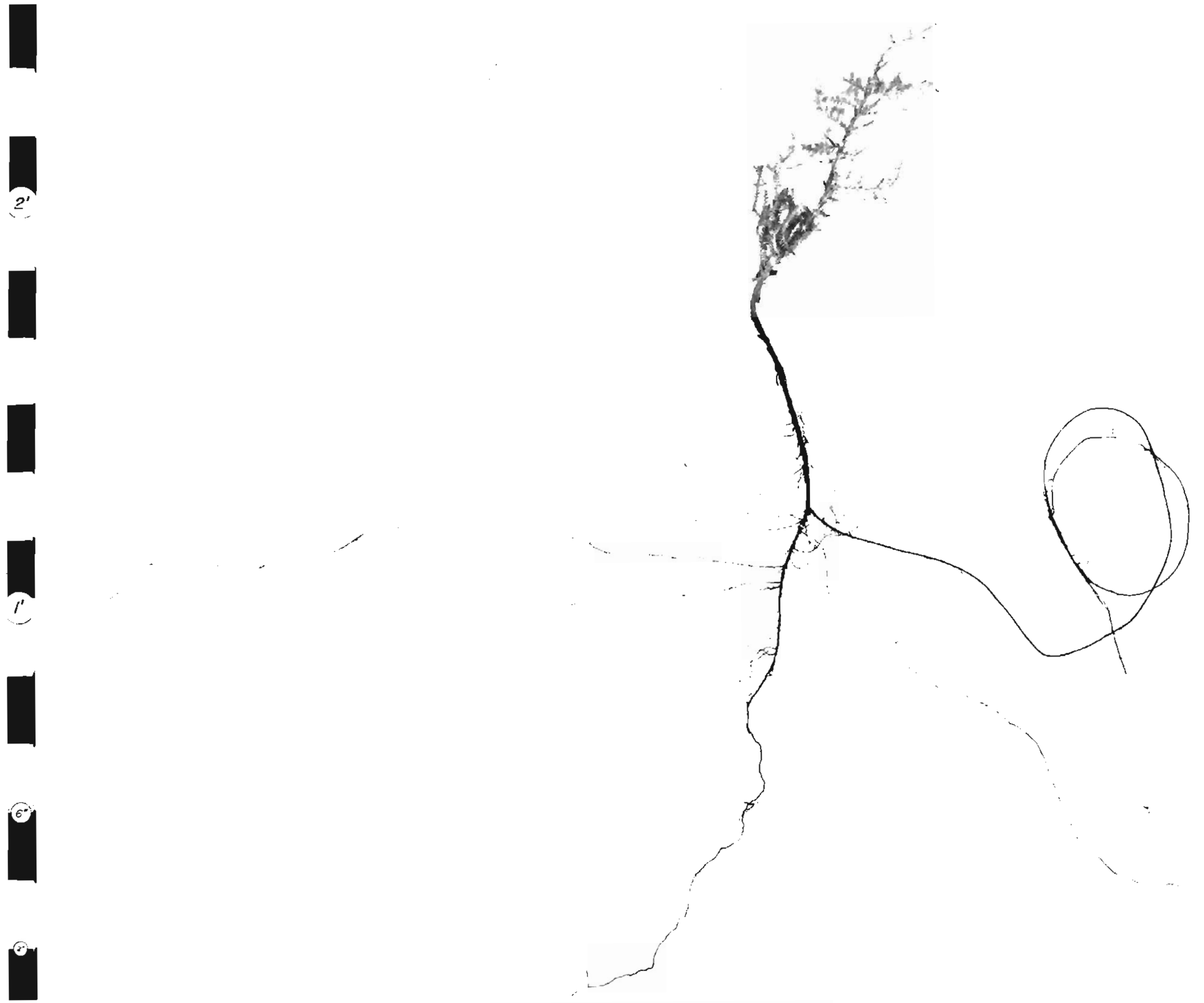


Figure 22. Western juniper seedling.

to the South and Southwest to be subject to major variations in rainfall or snowfall. In fact, there is no break in the topography over one-hundred vertical feet for twelve miles to the south, southwest, and west, the directions from which the storms move. One must go at least fifty miles in the directions from which the storms proceed to find elevations over 2,200 feet above the level of the Lost Forest. For the preceding reasons it appears justified to assume that Lost Forest is located in a precipitation zone similar to that of the adjacent areas. One variation of the Lost Forest from the general pattern is that due to thunderstorms which are of localized influence and which follow erratic paths. Figure 23, on which annual precipitation has been plotted for each year for each local station, shows good general agreement, however. United States Weather Bureau records (153, 154, 155, 156, 157) are the primary source of climatological information.

A United States Weather Bureau station at Cliff, located four miles west of the Lost Forest, was in operation for nine years--seven of those years concurrently with the Fremont station located in the western end of the Fort Rock portion of the lake basin (154). The latter station is still in operation. Thus a means of converting precipitation data for the Lost Forest vicinity was available. Except where otherwise stated, precipitation

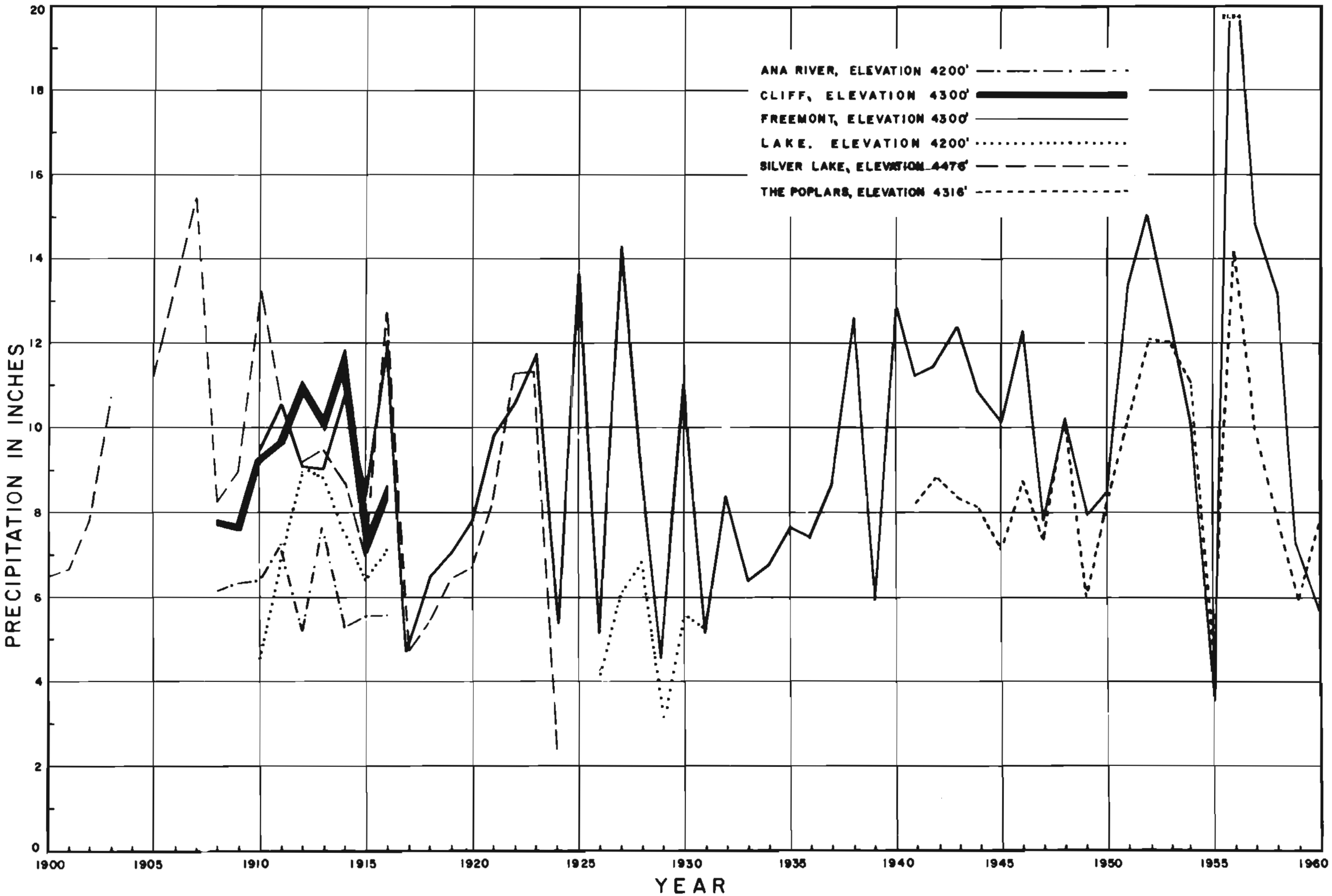


Figure 23. Annual precipitation at stations in Northern Great Basin in Oregon.

data given for the Lost Forest will be the direct observation taken at Cliff for the years 1908-1916 with the remainder of the years from 1900-1960 converted from Fremont (153) to the Cliff station. The conversion was based on the mean ratio of the two stations for the years of concurrent operation.

Annual figures are on an October to September basis rather than January to December basis. The mean annual precipitation thus projected for the years 1900-1960 is 8.74 inches. The mean determined by direct observation at Cliff during the years 1908-1916 is 9.62 inches. The difference is to be expected since the period of very low precipitation following abandonment of the Cliff station contributed greatly to lowering the long-term mean. The annual mean may also be compared to observations taken at the Poplars (156, 157) located several miles to the southwest (see Figure 1). The annual mean for the years 1941-1960 is only 10.66 inches, although the years 1941-1960 cover a period of much heavier than normal precipitation. The converted Cliff data provides a reasonably accurate approximation of Lost Forest precipitation. This is an essential point since any plant community normally requiring higher precipitation than that of the general region in which it is growing could conceivably be the result of a local variation in the general weather pattern. It seems quite conclusive that this is not a factor here.

The best observations on the snowfall are those made at Cliff during the years 1908-1916; these have been summarized from the data provided by Whistler and Lewis (160) (see Appendix 2). From these records and personal observations most of the snow has melted by the middle of March although snow may occur even into June. The monthly occurrence of precipitation for the Cliff - Lost Forest area is illustrated in Figure 24.

Considerable variation appears from year to year particularly during those months immediately proceding and during the growing season. The monthly occurrence of precipitation for all observation stations in the Christmas Lake Basin is summarized briefly in Appendix 5. Maxima for the months of January, February, May, June, October, November and December may be as high as three inches or more. Maxima for April, July, August and September are much lower. Minima in many months of the year may be zero or a few hundredth inches. Thus although trends are distinct, complete absence of precipitation to a maximum of several inches can normally be expected for any month.

The data from the Ana River station which was in operation at approximately the same time as the Cliff station were also analyzed for monthly maxima. There were three months in which the precipitation exceeded two inches.

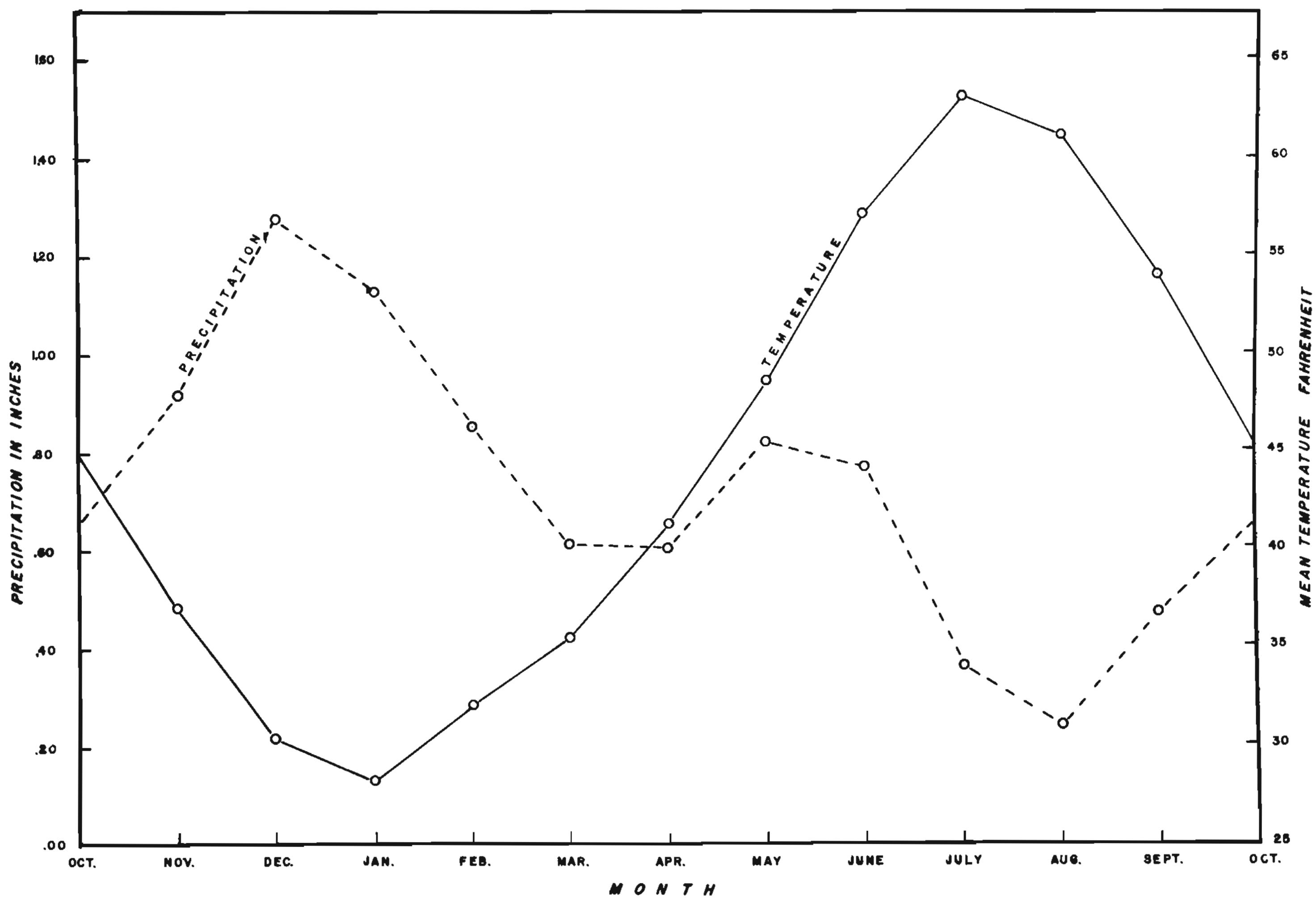


Figure 24. Monthly temperatures and precipitation means in Lost Forest.

Months with greater than .60 inches were fairly frequent.

The total quantity of rain occurring in each individual storm is of particular importance in characterizing the climate of desert and semi-desert regions. Light rains are quickly dissipated by evaporation into the dry atmosphere. Rainfall of a few hundredth inches may be entirely lost as far as replenishing the soil moisture is concerned. Total evaporational loss is not proportionally greater during more intense storms. Thus precipitation occurring in the heavier storms has a greater effect on soil moisture.

The data collected at the Fremont station for the years 1951-1960 have been analyzed for the relative amounts of precipitation occurring in storms of less than .20 inches and precipitation occurring in storms of greater than .20 inches for the months of February, March, April, May and June (Table 1).

Temperature - Local small scale differences in topography, ground surface cover, and other environmental factors often have a very profound effect upon temperatures. For this reason, no attempt has been made to convert temperature data from any of the stations to the Cliff or Lost Forest sites. Long term trends are applicable, however, and the data from other stations may also be used for the purpose

Table 1

OCCURRENCE OF PRECIPITATION IN STORMS OF OVER .20 INCHES AND UNDER .20 INCHES, FREMONT STATION

	FEBRUARY		MARCH		APRIL		MAY		JUNE	
	Amt. of Precip. in storms of		Amt. of Precip. in storms of		Amt. of Precip. in storms of		Amt. of Precip. in storms of		Amt. of Precip. in storms of	
Year	.20"+	.20"-	.20"+	.20"-	.20"+	.20"-	.20"+	.20"-	.20"+	.20"-
1960	.87	.40	.75	.28	--	--	.00	.63	.00	.05
1959	.98	.24	.20	.20	.27	.04	.21	.23	.00	.04
1958	--	--	--	--	.00	.48	1.12	.01	1.24	.60
1957	.53	.54	1.32	.68	.41	.36	1.00	.33	.00	.01
1956	1.60	.68	.00	.16	1.35	.00	3.45	.17	.53	.34
1955	0.00	.21	.00	.33	.61	.16	.00	.23	.00	.04
1954	.33	.07	.40	.33	.23	.29	.00	.08	.78	.28
1953	1.00	.36	.56	.36	.27	.13	1.70	.31	.51	.41
1952	1.64	.25	.21	.16	.21	.16	.64	.28	1.41	.59
1951	--	--	--	--	.00	.21	1.46	.21	.00	.05
Mean Percentage	71%	29%	58%	42%	65%	35%	79%	21%	65%	35%

of characterizing the climate of the Lost Forest and vicinity in a more general way.

Most of the forest is located on a long, gentle slope while many of the weather stations are located at the foot or close to such slopes and are probably more subject to the influence of cold air drainage. Mean temperatures for the Fremont, the nearest weather station, are shown in Table 2 for the years 1953 through 1960. The similar data are shown in Table 3 for the same period of years for The Poplars station, the only years during which complete temperature data are available. The mean temperatures are approximately 1.74° higher at The Poplars than at the Fremont station. These data do not provide a factor by which temperatures reported from other sites can be converted to Lost Forest values. They do indicate that a close relationship does exist among stations and that mean temperatures of The Poplars probably characterize the general area.

Temperature records also were kept at Cliff, four miles west of the Lost Forest. The mean temperatures are shown in Appendix 2, for each year between 1907-1915. These covered a period when no other complete records were available for any station now in operation. The only comparison possible is that of the Cliff temperature means for the period of 1908-1916 with the same data from The Poplars and Fremont for the current eight years (1953-1960). It

Table 2

MEAN TEMPERATURES AT THE FREMONT STATION

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1960	45.6	32.3	27.0	23.6	29.0	38.0	41.3	42.2	53.9	66.1	56.4	54.4	42.5
1959	44.6	35.9	26.0	32.9	31.2	35.7	40.1	42.7	54.3	62.7	57.2	50.6	42.8
1958	45.6	35.8	33.6	29.8	36.0	32.1	37.8	53.2	54.3	59.8	62.3	49.9	--
1957	42.2	32.3	32.5	18.6	30.6	39.1	40.3	50.1	57.5	57.6	55.4	56.9	--
1956	42.2	33.3	28.5	29.0	23.1	33.5	41.7	49.3	52.8	61.1	56.5	51.9	--
1955	46.9	32.2	28.6	20.5	28.1	31.9	32.9	44.0	55.3	55.0	57.1	51.5	--
1954	40.9	37.8	25.1	28.7	33.6	31.0	40.2	47.8	49.5	61.2	53.0	48.2	--
1953	45.0	40.2	32.9	35.5	33.4	33.5	37.3	41.7	46.9	58.7	56.4	58.7	--
Mean	44.2	35.0	29.3	27.3	30.6	34.4	38.9	46.4	53.1	60.3	56.8	52.8	

Table 3

MEAN TEMPERATURES AT THE POPLARS

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean
1960	45.9	33.1	28.7	24.2	30.0	38.8	41.4	46.2	57.1	66.4	59.8	56.6	44.0
1959	47.5	35.5	36.4	30.8	38.8	33.4	40.9	54.2	56.2	64.3	65.2	53.4	46.4
1958	47.1	36.8	26.2	33.0	32.6	36.6	44.1	45.0	57.3	65.4	59.7	52.0	44.7
1957	42.9	32.6	32.6	18.4	32.0	37.2	42.4	50.8	57.5	60.1	57.8	56.6	43.4
1956	43.2	35.1	31.0	28.5	26.1	35.9	43.5	50.9	53.1	63.6	59.3	54.0	43.7
1955	46.3	33.3	29.5	23.6	28.1	34.0	36.0	46.5	57.5	59.3	62.2	53.1	42.5
1954	43.1	39.4	27.2	29.9	34.7	32.3	42.6	50.5	52.0	62.3	57.1	51.4	43.6
1953	44.3	40.1	31.9	37.0	34.0	35.7	40.2	43.7	50.6	62.9	59.9	58.3	44.9
Mean	45.0	35.7	30.4	28.2	32.0	35.5	41.4	48.5	55.2	63.0	60.1	54.4	44.1

is found that the annual means of Cliff (1908-1916) are intermediate between the means of Fremont and The Poplars (1953-1960). It is obvious that such a comparison is valid for interpretations of climate during specific periods and for specific stations only. A comparison was made of the annual means for the same two periods in the records from Baker, Oregon. This shows a mean temperature of 44.98° for the period 1908-1916. The mean temperature at Baker for the period of 1953-1960 was 44.99°. Except for the possible influence of changing of immediate sites of stations, this would certainly indicate that overall temperatures during the two periods are quite similar. Therefore, we may assume that the mean temperature at the Cliff location is intermediate between the mean of the Fremont and of The Poplars. Figure 24 shows the monthly means for the Lost Forest Site.

As an example of the maximum temperatures of the Lost Forest, those reported by Whistler and Lewis (159) for the period 1908-1915 at Cliff are shown in Appendix 2.

The Tree Ring Record - The relationship of tree ring growth to changes in the normal precipitation pattern is too well known to require discussion here (9) (58) (74) (106). Tree ring growth is also subject to many other such influences as insects, disease, fire and mechanical damage. The effects of most of these, however, are of short duration. Short term influences in individual trees are evaluated or eliminated by adjusting to the annual growth rates of a number of samples. Such adjustments are made by matching a number of outstanding points in the annual growth rates to secure a minimum of disagreement. Individuals which display a strong deviation from the population trend are discarded.

Antevs (9) describes the relationship of tree ring growth to precipitation in several localities in the Great Basin. One of the locations was the Lakeview area where precipitation has been recorded since 1884. Tree ring data were taken from two different sites.

Antevs' charts show relative growth rates for the Lakeview vicinity from the year 1455 to 1930. From his data we find that the most severe drought condition since the year 1455 has been the recent one from 1920 to 1936.

The most comprehensive work in characterizing the climate of southern Oregon through tree ring analysis has been done by Keen (106). His studies were based on increment cores taken in the period between 1923 and 1936. One of the trees analyzed was 668 years old. The record thus begins in 1268 although for sixty-two years it is represented by but one tree. From the year 1330, however, he has analyzed not less than ten individuals to make up his tree ring calendar. In general his data agrees with Antevs', particularly for the long-term trends. No drought approaching the severity of that of 1920's and 1930's appears in his entire 668-year record. In the 15th century two relatively severe drought periods occurred but these were not of the magnitude of the recent one. In the same century (1415-1426) there occurred the highest positive departure from the mean in the entire period covered.

Recent Lake Records - The history of the Lost Forest and vicinity is intimately related to the status of the lakes of the area. For this reason the relationship of the recent climate to lake levels is extremely important. Silver Lake, located twenty-eight miles southwest of the Lost Forest has the most interesting and valuable history. Its record is also the most complete. The following records have been compiled from several sources (9) (38) (114) (159) (160):

WATER LEVELS OF SILVER LAKE

1877 -		Small remnant of once extensive body of water (6-7 miles by 2-4 miles)
1879 -	4'	Water alkaline, fish present
1882 -	12'	Had risen 6' since 1879, confluent with Thorn Lake
1889 -	0'	Lake dry, sagebrush found on bottom
1891 -	8'	Lake "filled," 9 x 12 miles in size confluent with Thorn Lake (Antevs)
1904 -	10'	Illustrated history "shallow enough to ride across."
*1905 -	12'	Overflowed into Thorn Lake
1908 -	6'	3 x 6 miles in size
1912 -	7'	Five feet below high water mark
1914 -	5'	Engineers measurement
1915 -	2'	Engineers measurement
1920 -	0'	Dried up
1920 - 51	0'	Dry
**1952 -	6'	Some rushes in center
**1955 -	9'	Lake filling
**1956 -	10'	Lake filled and covering highway
**1959 -	10'	Lake still covering old highway
**1960 -	8'	Lake level appears about as in 1955

* All surface stream flow taken for irrigation from 1905 to present.

** Author's estimate from direct observation.

The Silver Lake level fluctuations follow the three year mean of precipitation very closely and consequently are very closely related to tree growth variation.

Keen (106) also found that the level of Goose Lake near Lakeview corresponded to the departure from normal tree growth as determined by his tree ring study. Furthermore, he found that there was a good agreement with Columbia River flow as reported at The Dalles. These and other data indicate that lake levels as well as the general water supply of the basin is linked very closely with the mean of the previous three years' precipitation. It is also obvious that only a very slight increase in the precipitation over a period of several years could refill all the old lake basins. Of course, fluctuations in temperature could also change the effective precipitation by changing evaporation rates. Since tree ring growth should most accurately reflect moisture available after evaporation, Keen's and Antev's records should indicate with reasonable accuracy what the lake levels were for the past six hundred years.

The tree ring records and the known history of the lake levels in the basin indicate that modern Fossil, Thorn, Christmas and Fort Rock lakes were probably dry for most of the past seven-hundred years. They may have filled to levels of a few feet during certain years of higher rainfall. There were probably extensive shallow lakes in the old beds during the so-called little ice age which existed circa 1650-1850 (57).

That extensive filling of Fossil Lake has not happened within recent times is certain. Several pine trees approximately 150 years of age are now growing on the extreme eastern portion of Fossil Lake (see Figure 25A).

Climate of Wisconsin Glacial Period to Historic Times

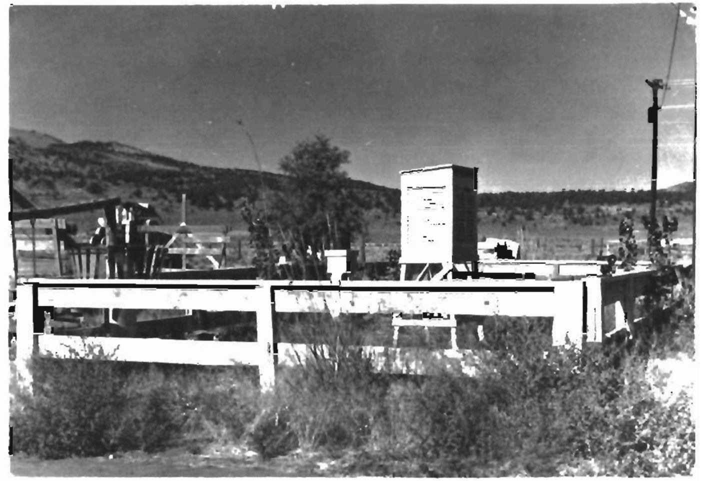
One of the important objectives established for the study of the Lost Forest was determining the source of the ponderosa pine which is disjunct from its normal range. One possibility for origin was the establishment through seeds reaching the area from the main body of a forest some thirty-five miles away.

A more likely explanation is that the pine forest is a relict of much more extensive forests which covered the land areas extending above the pluvial lake levels. In any event speculation as to the origin of the forest requires an interpretation of local conditions at least from the late Wisconsin glacial period to modern times.

Martin (117) speaking of such vegetational discontinuities states that most existing range gaps and relict populations date from the glacial period. In many cases, changes in precipitation and temperatures alone are adequate

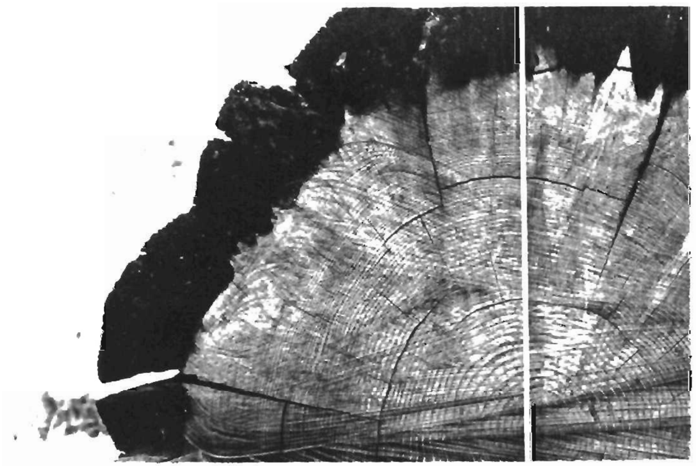
A

Pine on eastern portion of Fossil Lake.



B

The Poplars Weather Station.



C

Tree from dune showing rapid growth rate.

D

Fremont Station location, right background.

Figure 25.

to isolate species especially when mountain barriers and other physical barriers are present. In most of the larger great basins where exterior drainage does not permit removal of excess precipitation the physical barriers are most often in the form of lakes which change levels and boundaries frequently. Here, for instance, vegetation could respond to changes in precipitation and temperature and could be isolated by changes in the lakes which were themselves a result of climatic trends. The timing, distribution, quantities and other characteristics of volcanic effluvia also have their effect upon vegetation. For these reasons a careful interpretation of the climate and geological chronology of the general area is essential in serving the objectives of the study.

Although the continental ice sheet did not extend into Oregon during the Wisconsin Glacial Period there is no question that the cooler and wetter climate of the period had a very persistent effect upon both the vegetation and the landscape (64). The Wisconsin Glacial Period is commonly considered to have existed from 25,000 to 11,000 years ago. Four readvances together with intervening interglacial stages are recognized. The stages are Cochran, Monkato-Valders, Cary, and Tazewell (89). Suess (143) states that the maximum ice sheet advance was 17,000 to 18,000 years ago and that the ice sheet persisted until approximately 10,000 years ago. Libby's (109) radiocarbon dating of Two Creeks wood substantiates Suess' maximum of 17,000 to 18,000 years. Suess (148) arrived at his conclusion through analysis of sediments for relative content of two oxygen isotopes, O^{16} and O^{18}. The relationship of the quantities of the two isotopes in the remains of marine creatures which make up the sediments of the ocean floor was determined by the temperature of the water at the time of the animals' growth. Ocean temperatures are in turn indicative of concurrent land temperatures.

An absolute date for the disappearance of the continental ice sheet is not necessary since this study is concerned only with the area outside that covered by the ice sheet and is beyond the region subject to its melting waters.

The climatic effects, both direct and indirect, are extremely important. Precipitation during the glacial period was considerably higher than the present, particularly in the zone just south of the glaciated area. This was a result of an increased temperature gradient between the tropical areas (where evaporation probably abated only slightly) and the polar front which moved southward with the ice sheet (113) (52). MacGinitie (113) states that along glacial fronts, there were changes from tundra to broad-leaved forests and back again. Snow lines descended to 4,000 feet below the present snow line in New Mexico. Climatic changes were impetus for plant and animal disturbances. Isolated relicts were left scattered in favorable areas, south and probably west of the main occupied areas.

Martin (117) states that at least twelve inches precipitation is essential for forming an ice sheet. He estimated that an increase of nine inches of precipitation occurred in the Great Basin. He further states that summer temperatures which are sufficiently high to melt glaciers appeared to be a controlling factor. He postulates as much as 25°F lowering of temperatures in the glacial area. Martin estimates a July mean of 60°F at the ice sheet's lower boundary. This is $.5^{\circ}$F higher than the modern mean July temperature at Cliff but it seems probable that the temperature during the glacial period must have been lower than 60°F and that the precipitation then was also higher than the twelve inches postulated. From the fluctuation of modern lake levels it seems quite possible, however, that only small changes in total precipitation could have caused a considerable enlargement of current lakes and filling of dry lake beds, provided evaporation rates were reduced through lower summer temperatures. Flint (64) indicates that the mean temperatures during the pluvial period were about 8°C lower than today or the equivalent of

8-10° difference in latitude.

Conrad (37) states, the last two glacial stages have left a good growth record in the Great Basin in the form of shoreline features and lacustrine sediments. Dole (56) found in and near the Lost Forest two beaches at 4,470 feet elevation and 4,520 elevation. This is 120 and 170 feet above the bed of modern Fossil Lake. Dole correlates these two beaches with the last pluvial period and with lake levels of Summer Lake Basin.

Thus water at the highest level placed what is now the east end of the Lost Forest as an island at the eastern end of a large inland lake. As the lake filled during the early glacial period some of the plants were probably isolated here by the ascending waters rather than by later encroachment of the desert during post glacial times. The excellent drainage and aeration afforded by the beach sands could have permitted ponderosa pine to compete most favorably on the old beaches.

The sum total of the climate was perhaps best summarized by the vegetation in the area during the glacial period. Hansen (78,80,82) found by pollen analysis of sediment from Klamath Marsh, Summer Lake and Chewaucan Marsh that white pines were much more frequent in the lower sediments. Despite the fact that pine pollens are usually overrepresented in the pollen spectra (45) it is probable that white pine and other cold and wet climate species such as Abies, Larix and other genera covered most of the area above the lake levels. Hansen (81) states that during the late Pleistocene and early post glacial periods, forests covered a much greater area than at present and that the wider distribution was due to the moist climate that persisted there sometime after the glacial retreat to the north. Ponderosa pine was recorded as being predominant except in early post glacial time when white pine was most abundant.

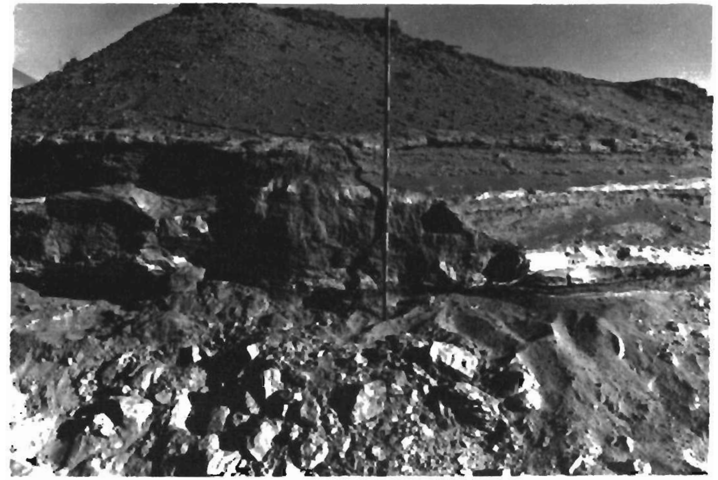
Many of the post glacial events in the Northern Great Basin of Oregon are marked indirectly by radio carbon dating of charred logs found under the pumice flow of Mt. Mazama. Mt. Mazama, whose crater is now occupied by Crater Lake, erupted 6453 ± 250 years ago (108). Great quantities of fine ash were distributed for considerable distances northeastward with the prevailing winds (164). Most of the material ejected was of a distinctive readily identifiable crystalline nature and thus serves as an excellent chronological marker wherever it was deposited in standing water and became a part of the lake sediments (164). (See Figure 26). The ash deposits have been particularly valuable in providing an absolute reference date for lake levels and pollen deposits (89).

Newberry Crater which erupted 2054 ± 230 years ago (109)

A

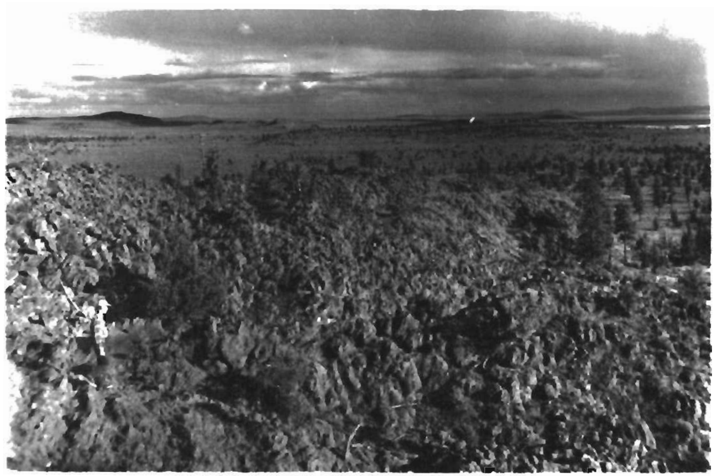
Basalt rim.

B



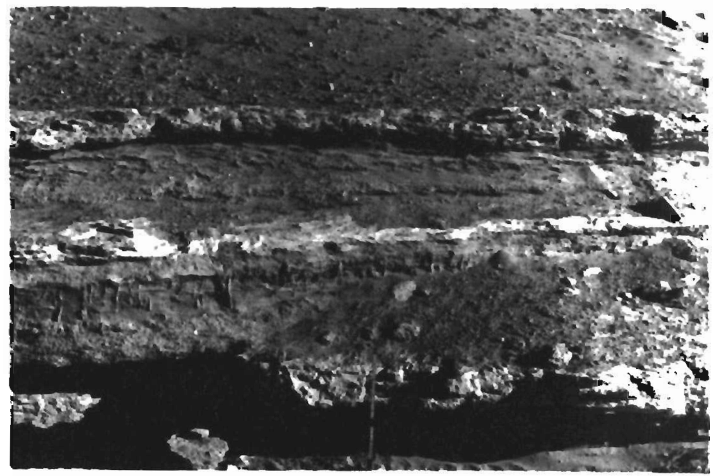
Fossil Lake ash sediments.

C



Pyroclastic breccia.

D



Close-up of Fossil Lake sediments.

Figure 26.

is also a factor in the chronology of much of the Great Basin but is of less significance to the immediate Lost Forest area. A gradual increase in temperatures occurred with the retreat of the ice sheet to about 8,000 years ago when a hot dry period, commonly referred to as the Hypsithermal Interval, began. This period persisted until approximately 4,000 years ago when cooler temperatures and higher precipitation returned, to remain relatively unchanged, until the present time (52) (57) (80) (82) (89). Pluvial lakes, however, persisted considerably after the end of the glaciers (81).

Lake levels not only affected the area occupied by the Lost Forest but when located in a closed basin are also good indicators of effective precipitation. Hansen (81) states that Mt. Mazama pumice was laid down in Winter Lake (the name given by Allison to Summer Lake's pluvial ancestor) when that lake was "several tens of feet" deeper than modern Summer Lake and Mt. Mazama pumice is found in "Fort Rock Lake" (the westernmost basin of Christmas Lake Basin). He writes that the Fossil Lake area was lower than the remainder of the lake bed and so a shallow remnant persisted there through the final waning periods beyond the time of the last ash falls.

Dole (56) has found a strata of crystal rich pumice in the Fossil Lake sediment which he has identified as being from Mt. Mazama thus indicating that the lakes persisted here at least as late as 6453 years ago and that precipitation at that time must have been somewhat higher than at present (Figure 26).

Dole also found another higher strata of pumice which had been deposited as an alluvial fan. He deduced that the latter was deposited by streams when the lake had almost disappeared. He thought the source of topmost pumice to be the Newberry Crater although he was unable to verify his conjecture conclusively. This indicates that a shallow lake existed at the boundary of the Lost Forest as late as 2054 years ago.

The exact sequence and combinations of temperature and precipitation as well as their seasonal patterns may never be completely known. Broecher et al (30) express the opinion that the mountain glaciers and ice sheets enabled maintenance of pluvial lake levels for a considerable period of time after the end of the glacial period proper. This seems improbable since temperatures sufficiently high to melt glaciers would also increase the evaporation rate and consequently tend to ameliorate effects of increased melting. It is more probable that a change in the temperature-precipitation relationship is responsible for these phenomena. A decrease in the portion of precipitation falling as snow with a slightly higher mean annual temperature is a much more probable combination of climatic conditions with which to account for a simultaneous retreat of the ice cap and the maintenance of lakes beyond the reaches of its melting waters. A change to cool cloudy summers with a decrease in snowfall could also account for lakes persisting after the glaciers.

An extension of mountain glaciers noted from about 1,650 to 1,850 A.D. has sometimes been designated as the "Little Ice Age." This phenomenon may have been the result of increased precipitation or increase in temperature or both. The tree ring record of Keen and Antevs in the northern portion of the great basin show no great increase in growth rates during those years, therefore it may be assumed that there was little or no change in the effective precipitation in the Christmas Lake basin during this period.

Hansen originally determined, on the basis of stratigraphy and pollen occurrence, that Mt. Mazama erupted from 5,000 to 7,500 years ago (80) (81). Williams (164) had dated the year of eruption at approximately five to six thousand years ago. Other workers placed the date much earlier. Hansen in order to acknowledge the overwhelming evidence for an earlier date fixed the eruption and its resulting pumice sediments in the lake beds and bogs at 10,000 years. Hansen's revised chronology is shown in

Table 4 along with the new dates assigned by him (89).

Table 4

POST GLACIAL PHYTO-CLIMATIC CHRONOLOGY
(89)

Years Ago	Northern Great Basin Climate Lakes and Glaciers	Northern Great Basin--vegetation	Lower Klamath Lake Vegetation	Occurrence of Volcanic Ash and Pumice
		Lodgepole Pine	Lodgepole Pine	
1000		Ponderosa Pine	White Pine	
2000	Rebirth of Lakes and Glaciers		Ponderosa Pine	Newberry 2054
- - -	- - -	(109)	- - -	- - -
3000		Grasses and Composites	Grasses	
4000	Cooler Moister	Grasses		
5000	Warmer than present	Chenopods Composites		
6000			Pond. Pine Maximum	Mt. Mazama 6453
- - -	- - -	(109)	- - -	- - -
7000	Disappearance of Lakes and Glaciers			
8000			Ponderosa Pine	
9000	Warmer		White Pine	
10,000			Lodgepole pine	
11,000	Pluvial Lakes			