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Thirty-Year Summary of Climatological Measurements from the Central Sierra Nevada

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ABSTRACT: In 1931 and 1932, five areas differing in aspect, elevation, and exposure were established near the Stanislaus-Tuolumne Experimental Forest to study local microclimatic variations. Data are still being recorded for one of these areas. The study showed how five areas of different aspect, elevation, past history, shade, and litter cover differ in air and soil temperatures, relative humidity, wind velocity, and precipitation. The extensive data summaries are available on microfilm.

Information on weather and climate serves many purposes in research. Foresters apply climatological and other data in determining site factors that may be important in silviculture. The failure of seedlings on one slope or their success on another, for example, may be the result of slight but significant climatic differences. Ecologists study the influence of climate on animals and plants.[1] Wildlife biologists are concerned with the effects of climate on animal growth and habits. The demand for long term weather data from mountainous regions far exceeds the supply, and the need to publish existing records continues to grow.

Since 1931, the Pacific Southwest Forest and Range Experiment Station has been studying the extent of microclimatic variations in local areas. In 1931 and 1932 Duncan Dunning and H. A. Fowells set up five weather or site-factor stations in the central Sierra Nevada, near the Stanislaus-Tuolumne Experimental Forest in Tuolumne County, California. Each five stations differed in elevation, aspect, and exposure.

[1] Lindsay. A. A., and Newman, J. E. Use of official weather data in springtime analysis of an Indiana phenological record. Ecol. 37: 812-823. 1956.

Records from three stations cover 11 years, another 19 years, and a fifth is operating today after more than 30 years. Data recorded include air temperature, soil temperature 1/4 inch and 7 inches below the surface, relative humidity, wind velocity, precipitation, cloudiness, and barometric pressure. Comparison of the five stations over the 11-year period gives some idea of climatic variability by site.

Kittredge's studies[2] on the influences of forest on snow were centered in the general area, and some climatological observations from the site-factor stations may have been used in his research. Some of the sampling sites for his snow studies lay close to site-factor stations 1, 2, and 4.

This note summarizes the highlights of climatological measurements from the five stations. The complete data have been compiled and microfilmed. A copy of the microfilm is available for inter-library loan from the Library, Pacific Southwest Forest and Range Experiment Station, P. O. Box 245, Berkeley, California, 94701. A copy also is on deposit at the School of Forestry Library, University of California, Berkeley.

CHARACTERISTICS OF GENERAL AREA

Geology. --The five stations lie near the South Fork of the Stanislaus River (fig. 1). Portions of the area included in this study show evidence of glaciation. Parts of the drainage are underlain by morainal deposits and the lower areas by river fill. A mixture of volcanic and granitic rocks carries through the moraines. The ridge tops consist of volcanic rock or granite.

Soils. --The soils are mainly sandy to fine sandy loam of the old Holland and Olympic series, well drained, and slightly acid. Their organic content differs greatly according to past history and present vegetation. Soil depth varies from 0 to 12 feet.

Vegetation. --The stations are in the mixed-conifer forest type. The main tree species include: Abies concolor (Gord. & Glendl.) Lindl.--white fir; Libocedrus decurrens Torr. --incense-cedar; Pinus Jeffreyi Grev. & Balf. --Jeffrey pine; Pinus lambertiana Dougl. --sugar pine;

[2]Kittredge, Joseph. Influences of forests on snow in the ponderosa-sugar pine-fir zone of the central Sierra Nevada. Hilgardia. 22(1): 1-96. 1953.

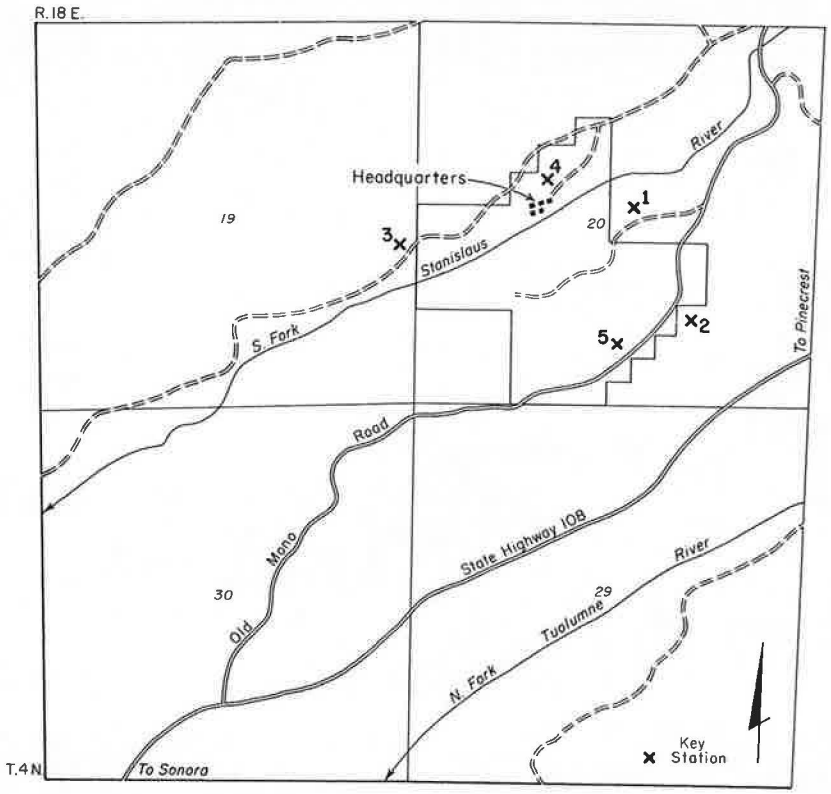

Figure 1. --Location of five weather or site-factor stations near the Stanislaus-Tuolumne Experimental Forest, Tuolumne County, California, within T. 4 N., R. 18 E., M.D.M. The test area lies south of Lake Tahoe and north of Yosemite National Park.

and Pinus ponderosa Laws. --ponderosa pine. Pinus contorta Dougl. (lodgeploe pine) occasionally grows in moist, cool sites, and Quercus kelloggii Newb. (California black oak) grows on drier sites.

The most common brush species include: Arctostaphylos spp. Adans. --manzanita; Castanopsis sempervirens (Kell.) Dudl. --Sierra evergreen chinkapin; Ceanothus cordulatus Kell. --mountain whitethorn; Ceanothus integerrimus H. & A. (C. andersonii Parry)--deerbrush; Ceanothus parvifolius (Wats.) Trel. --littleleaf ceanothus; Chamaebatia foliolosa Benth. --bearmat; and Ribes spp. L. --gooseberry.

The more abundant herbs include: Antennaria spp. Gaertn. --pussytoes; Calochortus nuttallii Torr. --segolily; Geranium spp. L. --geranium; grasses of many species; Iris hartwegii Baker--foothill iris; Lupinus spp. L. --lupine; Potentilla congesta Lemmon--cinquefoil; and Ranunculus spp. L. --buttercup.

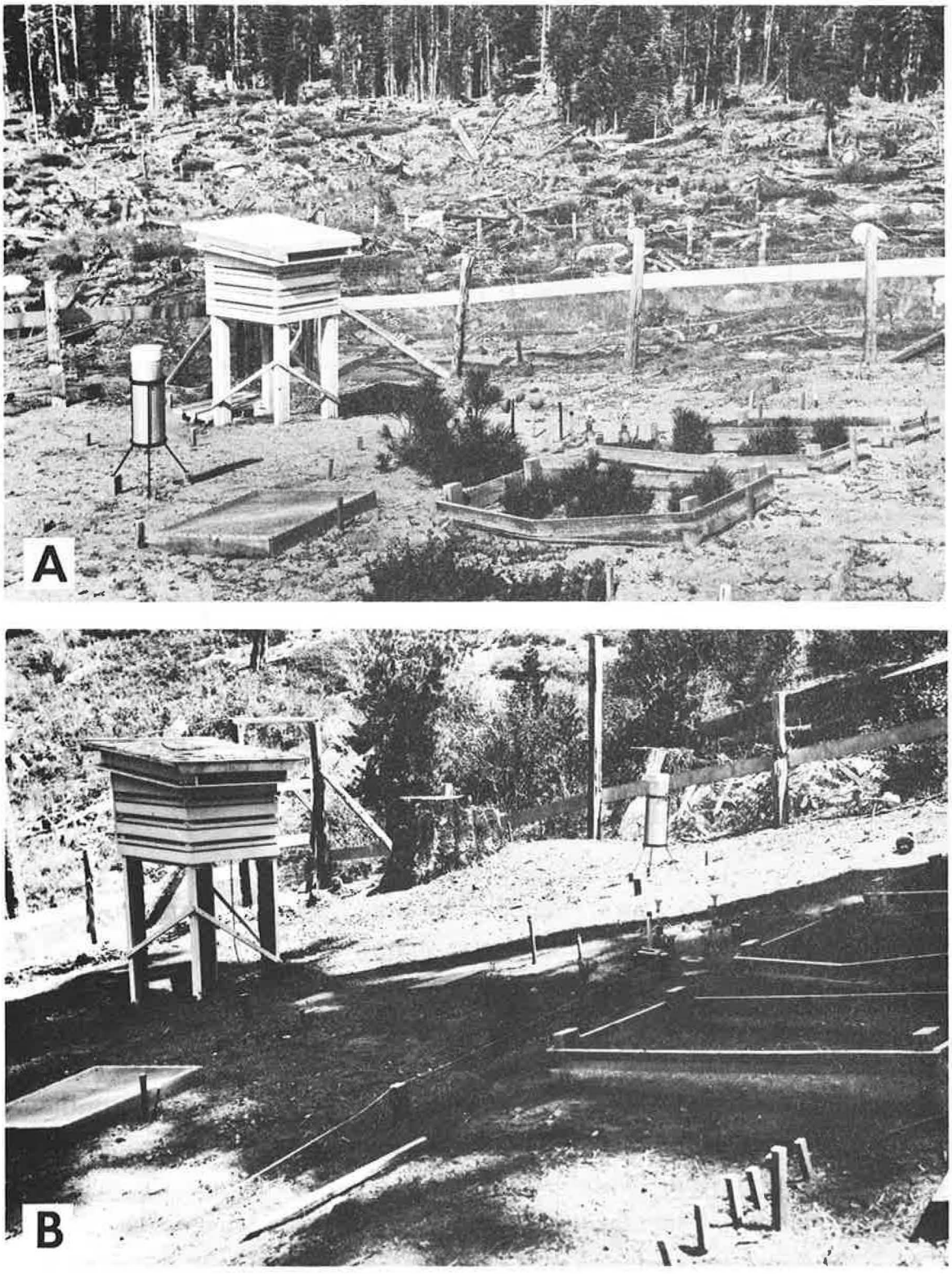

Figure 2.--A, Site-factor station 1 as it looked about 1934; B, site-factor station 2 as it looked about 1934.

The forest is dotted with open meadows and streaked with bare ridgetops. It is otherwise continuous but moderately open.

Climate. --The area has a summer-dry, winter-wet climate; most of the precipitation falls as snow. Air temperatures usually range from minus 10° to plus 95° F. during the year. The growing season is about 112 days.

SITE-FACTOR STATIONS

Each site-factor station was selected to represent a particular forest condition (table 1).

Station No. 1 was representative of north slope, clear-cut areas at 5,300 feet elevation surrounded by a sugar pine-fir type. It was in operation from 1932 to 1943. Located near the Old Mono highway and covering 1,848 square feet (fig. 2A), the station stands 75 feet above the South Fork of the Stanislaus River, 525 feet lower than the ridgetop. The slope is 18 percent to the north (25 degrees east).

The area was logged in 1927, leaving almost no large trees standing within 50 yards of the station. The soil was not cleared of debris, nor was the slash burned.

The station itself was cleared and raked clean and enclosed by a rodent-proof wire fence. The exposed mineral soil in the enclosure was kept free of weeds and debris (fig. 2A).

Full sunlight reached this north slope station, except from July 27 to September 4, when the only adjacent white fir cast an early morning shade for about half an hour during these months. The tree was blown down in the spring of 1936.

Table 1. Characteristics of site-factor station locations

Station	Elevation	Aspect	Slope	Exposure[1]	Date logged	Ground cover	Main species	Length of record
	Feet		*Percent*					*Years*
1	5,280	N	18	O	1927	Absent	Open	11
2	5,525	N	26	O-S	1928	Absent	Sugar pine, white fir	11
3	5,290	S	20	O	1927	Absent	Open	19
4	5,220	S	22	S-O	--	Present	Ponderosa pine	30
5	5,400	N	20	S	--	Present	White fir, ponderosa pine, sugar pine	11

[1] O= open, S= shaded. When two letters are shown, the first position shows the morning conditions and the second the afternoon exposure.

Station No. 2 also was in operation from 1932 to 1943. It was representative of north slope, partly logged areas at 5,500 feet. It is located about one-half mile southeast of the Experimental Forest headquarters and 400 feet above the South Fork of the Stanislaus River (fig. 2B), at an elevation of 5,525 feet. It has a 26 percent slope to the north (30 degrees west).

This north slope receives partial shade and lies on a partly logged hillside with much brush. The area was partially logged in 1928 by tractors, and the slash was piled and burned. The wire enclosure was cleared of debris in June 1932, leaving exposed mineral soil.

The original stand was sugar pine-fir. Rated Site I, it averaged 87,900 board feet per acre.

The composition of the stand after logging was:

	Area covered by trees after logging (percent)
Species:	
Ponderosa pine	8.4
Sugar pine	19.9
White fir	16.4
Incense-cedar	10.2
Total	54.9

Station No. 3 recorded weather data from 1933 to 1952. Originally the stand was Site I sugar pine-ponderosa pine. It represented an unshaded, clear-cut south slope at 5,300 feet elevation. The station lies one-quarter mile west of the Experimental Forest headquarters, 100 feet above the South Fork (fig. 3A), and 780 feet below Strawberry Peak, at 5,290 feet above sea level. It slopes 20 percent to the south (46 degrees east).

The station was shaded between 7 and 8 a.m., except during August; weak shade fell on the area at 1:30 p.m. during October and November. Otherwise, the 2,420-square-foot enclosure received full sunlight most of the day.

This area was logged by tractors in 1927. Slash was piled and burned, but some limbs and scattered debris remained. The enclosure was raked clean of debris before instruments were placed.

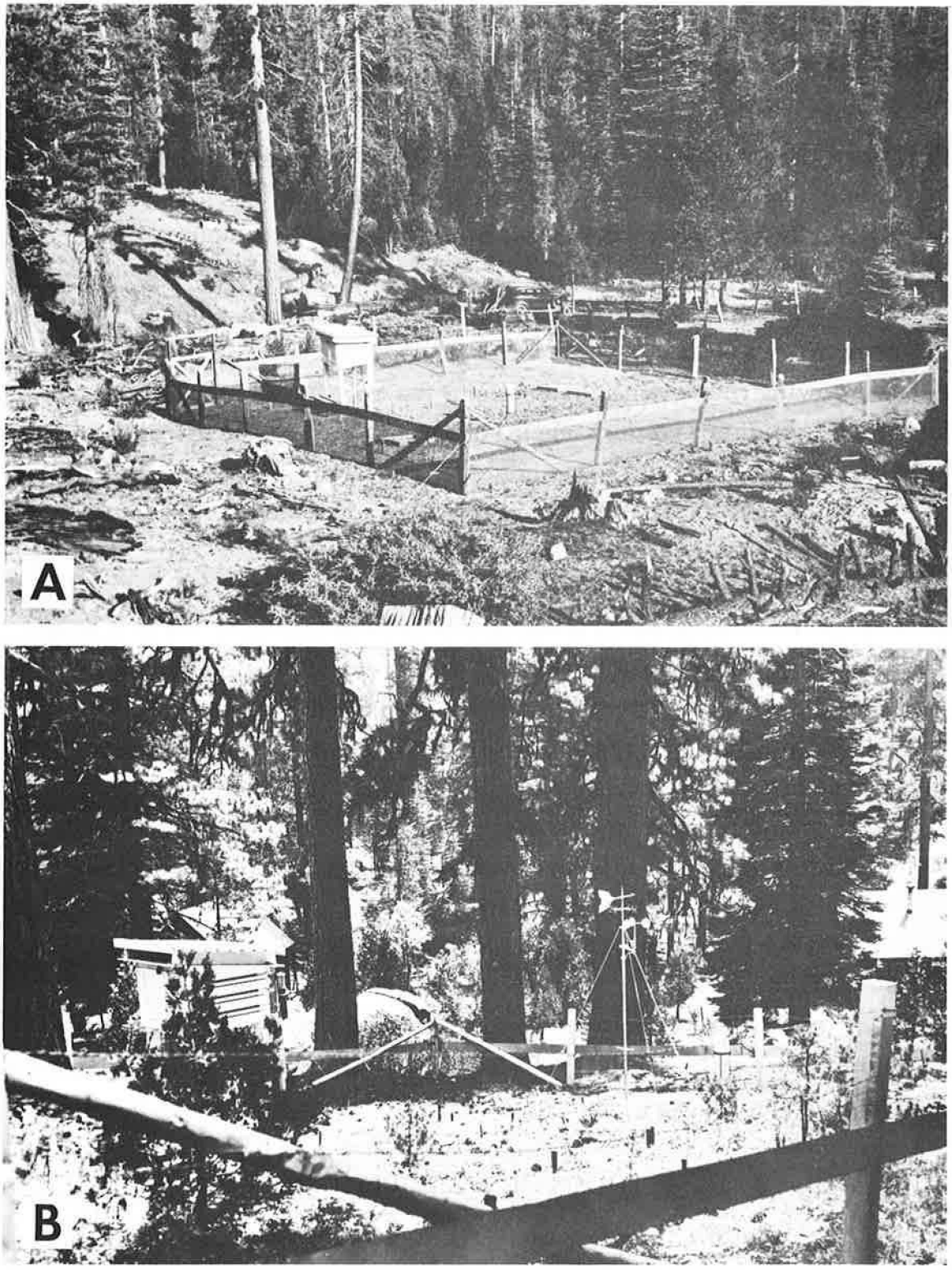

Figure 3. --A, Site factor station 3 as it looked about 1934; B, site factor station 4 as it looked about 1933 (late afternoon).

Station No. 4 represents an undisturbed south slope pine stand (22 percent south, 49 degrees east) which is moderately open. It has operated continually 12 months each year since 1933. It lies on the grounds of the Experimental Forest headquarters (fig. 3B) at 5, 220 feet elevation, 30 feet above the South Fork, and 850 feet below Strawberry Peak.

Station 4 is partially shaded in the morning, but the sun shines on the area after 1 or 2 p.m. Several large trees were removed about 1950, allowing more sunlight to reach the soil in the afternoon and resulting in higher temperatures. About 30 percent of the area of the station receives sunlight for 5 hours a day in summer.

This area is mainly unlogged. The enclosure surrounds a litter-covered area with one large ponderosa pine in the plot. The stand is Site I ponderosa pine and had an average volume of 29, 300 board feet per acre in 1927. The area as a whole would probably have 50, 000 board feet per acre. The trees are 160 to 200 feet high and range in height to crown from 20 to 60 feet. Numerous small trees grow in the openings.

Station No. 5 represented a heavily shaded north slope (20 percent north, 30 degrees west) at 5, 400 feet in a white fir pole stand with scattered mature sugar and ponderosa pines. Located along the Old Mono highway (fig. 4), 275 feet above the South Fork, and 325 feet below the ridge, it was operated from 1932 to 1943.

Station 5 was heavily shaded by a dense pole stand of white fir and several large pines. Neither the original stand nor the litter has been disturbed. The enclosure was cleared of large limbs before the instruments were installed. The adjacent stand is mainly sugar pine-ponderosa pine. It was rated as Site I and averaged 33, 325 board feet per acre in 1927.

METHODS OF MEASUREMENT

Each station had a white slat-sided shelter with louvered door (standard U. S. Weather Bureau type) set within an enclosure so that the floor was 4. 5 feet above the ground.

The following data were recorded at each station:

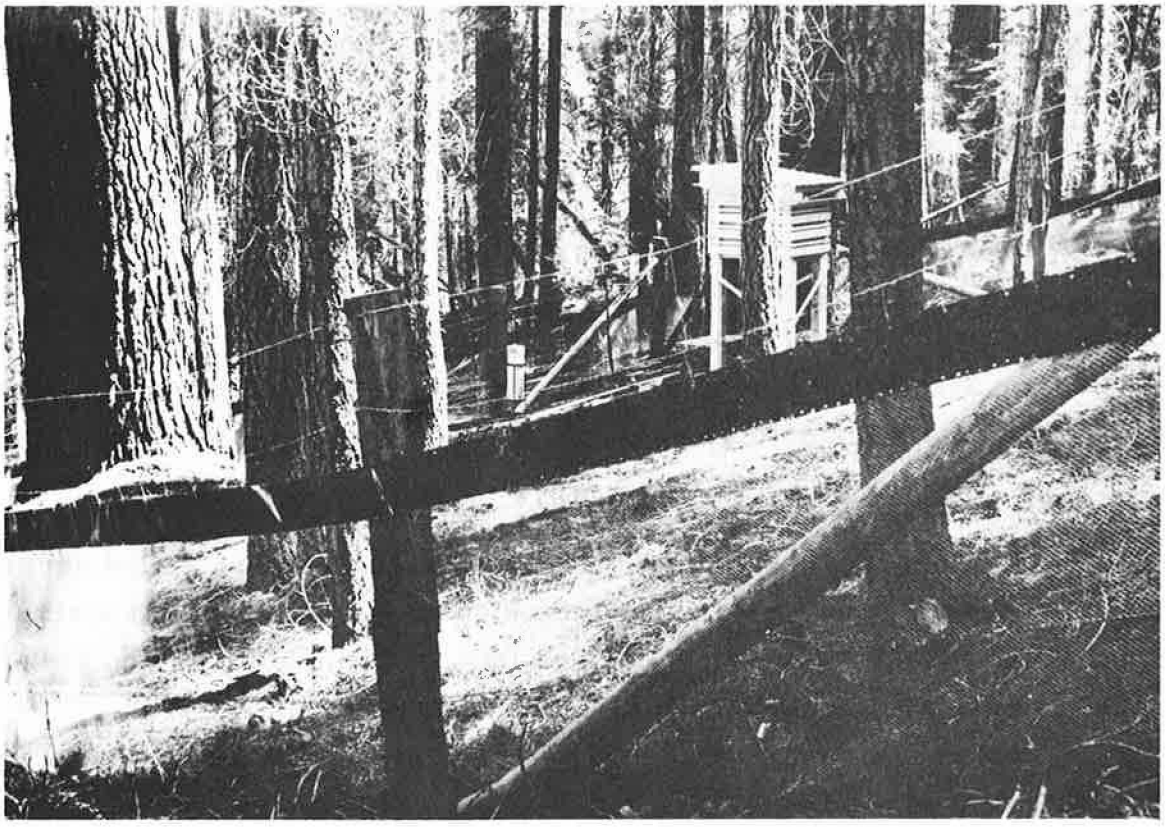

Figure 4.--Site-factor station 5 as it looked about 1935 (morning sun).

1. Air temperatures within the louvered shelter at 4.5 feet above ground--by a hygrothermograph checked daily by maximum-minimum thermometers.

2. Relative humidity within the louvered shelter at 4.5 feet above the ground--by a hygrothermograph checked daily by a psychrometer.

3. Barometric pressure at 5,220 feet elevation--by a barometer in the shelter of station 4 only.

4. Cloudiness--degree of cloudiness observed each morning.

5. Wind velocity (miles per day) at 8.5 feet above the ground--by a 4-cup anemometer at station 4 only.

6. Precipitation, in inches per storm--by an 8-inch rain gage (includes precipitation as snow).

7. Soil temperatures at 1/4-inch and 7-inch depth--by two 1-lead thermographs.

8. Soil moisture determinations at 0 to 3, 6 to 8, and 18 to 21 inches during the summer--by the gravimetric method (10 years--H. A. Fowell's data).

Daily observations were usually made between 8 and 10 a.m. For the first few years, records were taken only between May and October. All stations were serviced on Monday morning.

Months were generally divided into 10-day periods (decades) from the 1st through the 10th, the 11th through the 20th, and the 21st through the 30th or 31st. Any period with less than a 6-day record was not used. Inaccurate data were deleted. Some records were quoted for full months.

TEMPERATURE, PRECIPITATION, HUMIDITY

Air temperatures. --The lowest air temperature recorded during the 30-year period was -14° F. and the highest 101° F. --both at station 3. On the average, the last 10 days of July were the hottest, and the middle 10 days of January were the coldest.

Table 2 lists the average air temperature (based on 29 years) for each month at station 4.

Table 2. Average monthly maximum and minimum air temperatures based on 29 years, station 4, 1933-1962

Month	Average °F.	
	Minimum	Maximum
January	19.8	45.0
February	21.1	45.9
March	23.8	49.8
April	28.5	57.4
May	32.7	64.4
June	37.7	72.3
July	42.8	81.8
August	40.1	81.6
September	36.4	76.7
October	30.8	65.7
November	24.5	55.8
December	22.2	47.8

Over the 30-year period, a pronounced increase in heat occurred at station 4. This difference became noticeable between 1950 and 1952. The change probably resulted from the removal of a nearby tree, which previously shaded the ground in the afternoon.

The five stations ranked as follows from warmest to coldest: 3, 1, 2, 4, 5. Both extreme and average soil and air temperatures fell in this order.

Soil temperatures. --The highest 1/4-inch soil temperature of 160° F. was recorded in 1943 at station 3; the lowest in 1942, at station 4, when lack of snow cover in February allowed the soil to cool to 3° F. Seven-inch soil temperatures remained in the low 30's throughout most of the winter and rose to the 60's to 80's on the south slope in late summer. After the first lasting snowfall, the 1/4- and 7-inch soil temperatures remained within 2 or 3 degrees of one another (29-32° F.). In spring just after snowmelt and in fall just after snow fall, the maximum and minimum temperatures in both soil depths occurred at midnight, 24 hours apart. Both of these cooling and warming phases varied in time of occurrence and length, and appeared to be related to shade and the depth of snow cover.

In general, the time of maximum soil temperature at the 1/4-inch depth shifted from about 2:30 p. m. in January to 1:30 p. m. in June, and fell later each month until snow again prevented temperature variation during the entire day. The average time of maximum heat varied from 1:20 to 2 p. m. at station 4 for the entire year. Minimum 1/4-inch soil temperatures occurred any time from midnight to 7 a. m. Air temperatures followed a similar pattern, but reached extremes earlier than soil temperatures. Areas more exposed than station 4 reached extremes slightly earlier. Station 5 was much slower to warm up and cool off than the other sites.

Station 5 had the lowest maximum and minimum 7-inch soil temperatures. Dense shade limited the heat reaching the soil and the amount of reradiated energy. The unrestricted amount of radiant energy reaching or leaving the exposed soil of station 3 accounted for the annual fluctuations of soil and air temperatures--the greatest of any station. Station 1 was similar to 3, except that it was on a north slope and received

less total heat energy. The semiopen location of station 2 accounted for its temperature range. Deep litter and partial shade lowered temperatures at station 4 even though it was on a south slope.

Soil temperatures at one-fourth inch on the open south slope may stay above 80° F. for 9 to 10 hours, above 100° F. for 6 to 7 hours, above 120° F. for 5 to 6 hours, and over 130° F. for 3 to 4 hours during a hot day in late July.

In a hot year, such as 1939, station 3 on the south slope totaled nearly 1,400 hours above 80° F--measured at one-fourth inch of soil. In the same year, the open north slope of station 1 recorded only 1,018 hours above 80° F. The shaded south slope at station 4 had only 449 hours above 80° F. in 1939, and the densely shaded soil of the north slope of station 5 rarely exceeded 80° F. in the 11 years of records.

Relationships.--Preliminary attempts to relate soil and air temperatures showed that 7-inch soil temperatures were more reliable for correlation. Relationships between air and soil temperatures can be established statistically, but the problem is to determine the best time interval--hours or days--and whether average or extreme temperatures should be compared.

Although stations 3 and 5 were less than a half mile apart, soil temperatures differed as much as 66° F. (table 3). In the hottest year (1943) these same stations differed in extreme soil temperature maxima by nearly 80° F. The differences in air temperature, mainly the result of aspect and shade, were much less (only 5° F.) because of free air circulation.

Humidity.--As expected, station 5 maintained higher relative humidity minima (rarely below 15 percent at noon) than any of the other stations. Station 3 had the lowest midday relative humidity. Most stations recorded 90 to 100 percent humidity near dawn.

Wind.--The least daily wind (about 0.5 to 5.0 miles per day) occurred in December, January, and February. However, small amounts of daily wind travel are difficult to measure accurately because anemometers have appreciable starting speeds and do not respond to wind velocities below the threshold. The windiest months were April, May, and June, although winds in July and August may register 15 miles per day.

Table 3. Differences in air and soil temperatures at the five site-factor stations, 1940

Station No.	Extreme soil temperatures at:				Extreme air temperatures at 4.5 feet		Average hours/summer day at 1/4-inch soil depth over:			
	1/4 inch		7 inches							
	Max.	Min.	Max.	Min.	Max.	Min.	80°F.	100°F.	120°F.	130°F.
	Degrees F.									
1	146	6	74	28	[1]92	[1]13	6.9	4.7	3.4	2.6
2	140	21	--	--	[1]90	[1]19	6.8	3.9	2.1	1.4
3	156	10	81	30	93	5	7.4	6.0	4.7	3.9
4	127	[1]28	66	32	92	8	5.0	1.1	0	0
5	80	20	--	--	[1]87	[1]19	0	0	0	0

[1] *Incomplete records.*

Precipitation. --The most precipitation falling in any year was 63.4 inches in 1950. The driest years were 1938, 1939, and 1949 when about 20 inches of precipitation fell each year. The months of highest precipitation were January, February, and December, in that order. The driest months were September, followed by August, July, and June (all data from station 4). December, January, and February were the cloudiest months. Average annual precipitation over a 26-year period was 36 inches. Comparison of precipitation by stations is difficult because of interception and stem flow which were not measured.

COMPILATION OF DATA

The compilation of data on microfilm consists of 485 pages, divided into three sections. Each section includes a number of graphs. The basis of summary, instrumentation, station, and length of records for each type of measurement are tabulated in the introduction of the microfilmed copy. The measurements available include:

Air temperatures:

- Maximum, minimum, and average.
- Extreme maximum, extreme minimum, and range.
- Average maximum, average minimum, and monthly range of extreme averages.

Time and temperatures:

- Period in which annual maximum soil and air temperatures occurred.

Average hour of occurrence of temperature:

- Maximum and minimum air temperatures.
- Maximum and minimum at 1/4-inch soil depth and 7-inch soil depth.

Extreme air temperatures:

- Maximum, minimum, and range.

Comparative extreme and average soil temperatures:

- Maximum and minimum at 1/4-inch soil depth and 7-inch soil depth.

Comparison of extreme and average of extreme temperatures:

- Extreme maximum and minimum air temperatures, average maximum and minimum air temperatures.
- Extreme maximum and minimum, average maximum and minimum soil temperatures, 1/4-inch soil depth and 7-inch soil depth.

Soil temperatures--1/4-inch depth and 7-inch depth:

- Extreme and average maximum and minimum.

Soil temperatures--1/4-inch depth:

Total and average hours above 80° F., 100° F., 120° F., and 130° F.

Daily average number of hours above 80° F., 100° F., 120° F., and 130° F.

Annual total and average number of hours above 80° F., 100° F., 120° F., and 130° F.

Weather data:

Relative humidity--maximum, minimum, and range.

Percent soil moisture.

Precipitation--average, total, maximum, minimum, and annual total.

Wind--maximum, minimum, average, and total.

Number of cloudy days.