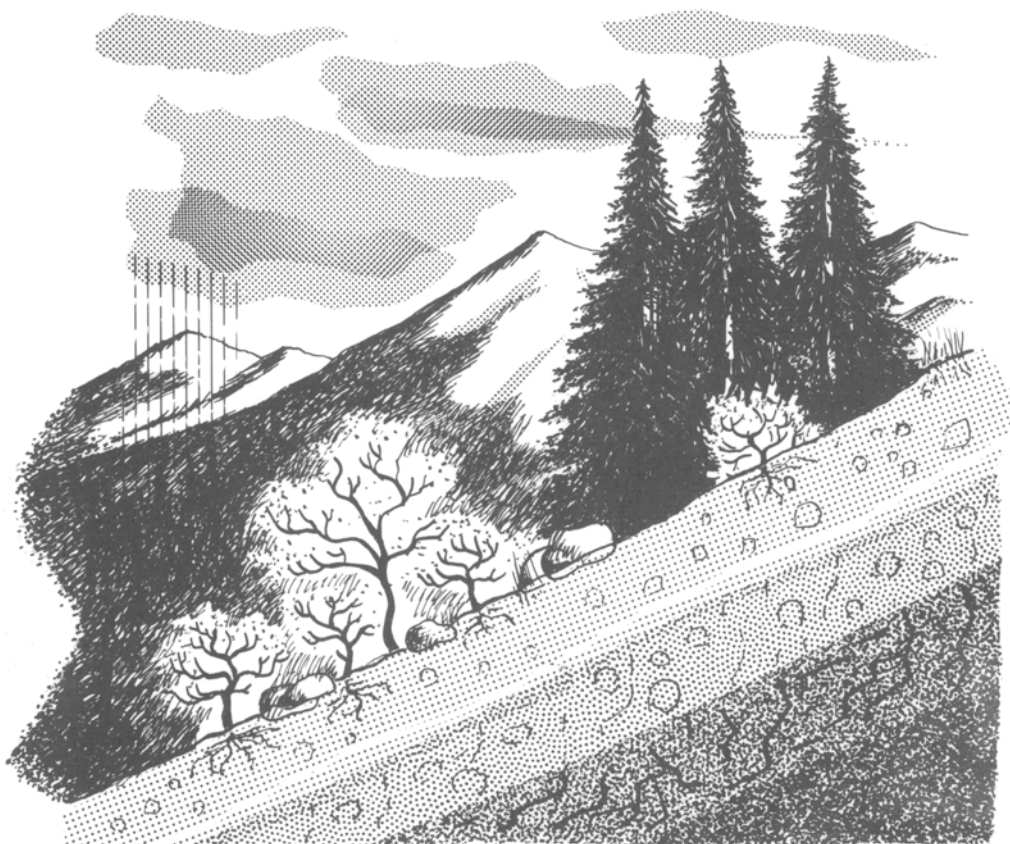


# Soil Moisture and Vegetation Patterns in Northern California Forests



U.S. FOREST SERVICE RESEARCH PAPER PSW-46

1967

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Pacific Southwest Forest and Range Experiment Station  
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Griffin, James R.

1967. **Soil moisture and vegetation patterns in northern California forests.** Berkeley, Calif., Pacific SW. Forest and Range Exp. Sta. 22 pp., illus. (U.S. Forest Serv. Res. Paper PSW-46)

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*Retrieval Terms:* soil moisture tension; soil-vegetation patterns; California pine forests; California mixed conifer forests; vegetation drought index (VM); soil drought index (SDI); Cascade Mountains.

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James R. Griffin

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**The Author**

**JAMES R. GRIFFIN** was plant ecologist on the Station's silvicultural research staff, headquartered at Redding, Calif., from 1962 to 1967. Educated at the University of California (B.S. 1952, M.S. 1958, Ph.D. 1962), he is now with the University's Hastings Natural History Reservation, Carmel Valley, Calif.

***Acknowledgments***

I thank the following organizations for permission to sample soils and vegetation on their lands: Kimberly-Clark Corporation, Shasta Forests Company, California Division of Forestry, Lassen National Forest, and U.S. Bureau of Land Management. Dr. Richard Waring, Forest Research Laboratory, Oregon State University, furnished many ideas for the study.

California has 3.8 million acres of commercial forest land classified as less than 10 percent stocked (Oswald and Hornibrook 1966). Much of this land supports only brush, and evaluating the productivity of such potential timber sites is next to impossible with no trees to measure. This paper reports a study seeking leads to alternative indexes of site quality. Basically, the study describes ecologically significant levels of soil moisture in a commercially important forest area with little literature in descriptive plant ecology.

Trends from a soil moisture survey are related to plant distribution and forest productivity in general terms. The usefulness of plants to indicate moisture conditions is also tested against the soil moisture data. Although the approach has wide application, specific soil-plant relationships should not be extended too far. Specific results should apply to most upland forests on basic igneous rocks between Mill Creek and the McCloud River (*fig. 1*). In more general ways the data may be useful in the region between the Feather and Klamath Rivers (*fig. 1*).

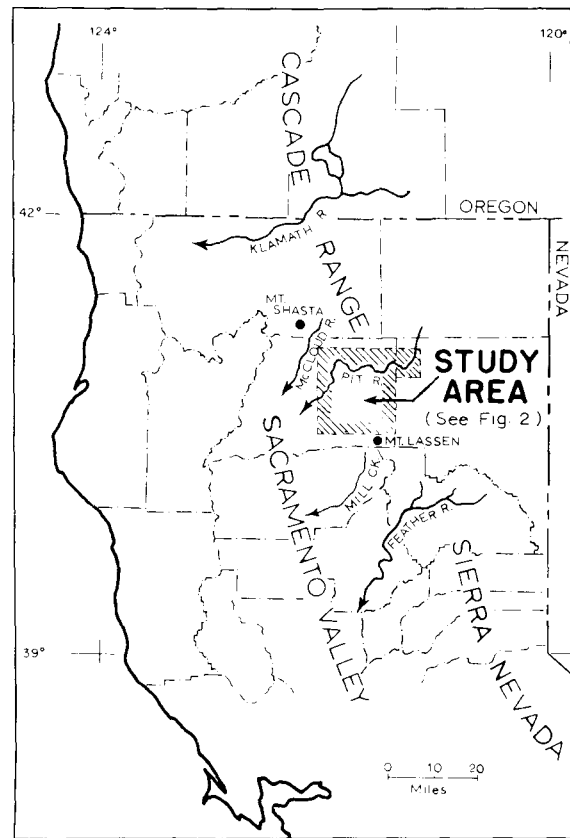


Figure 1.—General location of the study area in northern California.

## Relevant Studies

### **Moisture Gradients and Plant Indicators**

Whittaker (1960) described a large number of vegetation plots on several rock types in the western Siskiyou Mountains in Oregon. Many species which he discussed grow on my plots. His plots were aligned along a moisture gradient estimated from topographic position. The wettest class was assigned to deep ravines with flowing streams. The series ended with dry plots on open south and southwest slopes. Whittaker's methods help us understand vegetational relationships over a large area. But adding direct measurement of soil moisture conditions to this sort of qualitative survey is desirable. Topographic estimates of moisture conditions are also less helpful on the gentle slopes of eastern Shasta County than in the steep Siskiyou topography.

In the California redwood region, Waring estimated the available moisture regimes in 10 vegetation types (Waring and Major 1964). These vegetation types are not closely related to those in this study, but a few species common in the redwood region do play a minor role in Shasta County vegetation.

Waring followed soil moisture depletion during two summers with gravimetric samples. After determining bulk density, rock volume, wilting point, and field capacity of the surface meter of soil, he calculated the storage capacity at each plot. He found no usable relation between total storage capacity and vegetation type. After converting his data into an available moisture index, he found that all of his upland plots had a meaningful distribution along a gradient in minimum index values.

Cleary<sup>1</sup> extended Waring's methods in the Oregon Cascades. His five plots along a local moisture gradient showed a high correlation between soil moisture conditions and understory vegetation. Cleary did not investigate percentages of storage capacity. Instead, he used maximum soil moisture tensions. He determined field moisture content of the 5 mm. or less fraction of 40-cm. depth samples. After developing soil moisture tension curves from the sample material, he converted field moisture contents to tensions. This aspect of his work is similar to the method independently developed in this study.

Rowe (1956) described in detail one method of deriving a moisture gradient from vegetation studies in eastern Canada. He suggested that the:

1. Method must be simple; little more than recognition of species can be expected from practical users.
2. Some insensitive species occupy a wide range of habitats. Their broad ecological distribution makes them of little value as indicators.
3. Rare plants should be used cautiously because of the danger that they are temporary invaders from outside the community.
4. The ecological distribution of very mesic species is often narrower than that of xeric species. Mesic species should be given more weight.

In practice, Rowe listed all plants in the stand under study. He deleted the most widely distributed species from the final calculations. If the total number of sensitive species dropped to about 20, he used rare species. Rowe then assigned each species to a numerical moisture group and computed an average value.

Waring has applied this type of work to California conditions (Waring and Major 1964). He called the point along a soil moisture gradient where a species' highest population density occurred the "ecological optimum." Ecological optimum data guided his assignment of species to seven moisture groups. In calculating his final index, Waring tallied the species from each group present on a study plot and averaged all the figures giving an over-all minimum available moisture index.

Waring also tested indexes weighted by population density. He stated that ". . . because fre-

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<sup>1</sup>Cleary, B. D. *A microsite study of vegetation in relation to a soil moisture gradient*. 1964. (Unpublished report on file at Oregon State University, Corvallis.)

quency and relative composition of the overstory are strongly influenced by factors not related to moisture regime, the index based on species presence . . . is recommended as having the most widespread utility. In addition to being better adapted to use on cutovers and other disturbed sites, it has the added advantage of simplicity." This study is a good test of the use of a species "presence" index in disturbed sites.

## **Local Soil and Vegetation Work**

### **Soil-Vegetation Surveys**

Most information about forest soils and vegetation in the study area has been produced by the California Cooperative Soil-Vegetation Survey.<sup>2</sup> Maps like those by Mallory and Alexander (1965), Mallory *et al.* (1965a) and Mallory *et al.* (1965b) give generalized data on soil series classification, soil depth and rock content, and site quality for many of my study plots.

Most National Forest lands were not mapped in Shasta County. Mapping on private lands can be extrapolated to some plots on Federal lands. Of particular value for the higher elevation plots were the more detailed soil-vegetation maps and report for Latour State Forest (Gladish and Mallory 1964).

The California Soil-Vegetation Survey has published little interpretive material. But in a general account of California forest soils, Zinke and Colwell (1965) did use Soil-Vegetation Survey data from within the study area (near plot 15) as the volcanic rock example in a soil development discussion.

A special soil survey<sup>3</sup> on a small area of Shasta soil series on Mount Shasta may have some application to soil problems on some Shasta-like soils northwest of Mount Lassen.

Limited soil survey<sup>4</sup> information is available for the area east of the study area near Blacks Mountain.

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<sup>2</sup>Soil-vegetation maps and legends mentioned in this paper available for purchase from the Regional Forester, U.S. Forest Service, 630 Sansome Street, San Francisco, California 94111.

<sup>3</sup>Conlin, B. J. *Report on soil-vegetation investigations of the Mt. Shasta brush fields tree planting project, Shasta-Trinity National Forest*. 1963. (Unpublished report on file at California Region, U.S. Forest Service, San Francisco, Calif.)

<sup>4</sup>Soil survey of Blacks Mountain Experiment Forest. 1940. (Unpublished map compiled by University of California soil science students on file at Pacific Southwest Forest and Range Exp. Sta., Redding, California.)

### Soil Moisture Studies

No detailed, ecologically oriented soil moisture study has been conducted in the study area. Several surveys in the past have sampled soil moisture within forest stands. For example, in the 1930's, forest entomologists tried to relate bark beetle hazard to moisture and other environmental factors. Their sampling methods and results, however, are difficult to relate to this investigation.

As part of a brush conversion project near the western end of the study area, gravimetric soil moisture samples were taken for several seasons (Adams, Ewing, and Huberty 1947; Veihmeyer and Johnson 1944). Data from their "Oregon Oaks" plot (on Aiken soil series) and "Gleason" plots (on poorly developed Cohasset soil series) showed that by mid-July the woody vegetation on undisturbed chaparral plots had removed all of the available moisture in the profile.

The most useful soil moisture study bearing on this project came from the Stanislaus-Tuolumne Experimental Forest in Tuolumne County (Fowells

and Stark 1965). Although situated on granitic rocks of the central Sierra Nevada, its mixed conifer forest is closely related, ecologically and floristically, to the mixed conifer forest in Shasta County.

Soil moisture was sampled on the Experimental Forest at weekly intervals from May to October on five different plots for 8 years. Wilting points of the soil samples were established using sunflowers. Two of the plots were uncut, and their results are most applicable to this study. Moisture under a dense stand on a north aspect was above the wilting point all summer every year. Moisture in the other uncut plot on a south-facing slope dropped below the wilting point at least 1 month each summer. In the dry year of 1937 it was at or below wilting point to a depth of 101 cm.

Although the methods were relatively crude, distinctly different soil moisture regimes were documented at the Experimental Forest. The greater diversity of forest types in the larger Shasta County study area should yield sharper contrasts in soil moisture regimes.

## Sampling Methods

### Plot Selection

The study area lies in Shasta County near the southern end of the Cascade Range (*fig. 1*). Thirty-seven plots within this area sampled a broad transect across the main ridge (*fig. 2*). All important upland forest soil series were included (*table 1*). Most data were derived from 29 "regular" plots that were studied for 3 years. This material is strengthened by eight "supplementary" plots studied for one season.

Studies of this type usually sample "undisturbed" forest stands. Measures of dominance in stable climax communities would have more statistical validity than data from disturbed habitats. Unfortunately, virgin forest is no longer available at lower elevations in Shasta County. Representative forest samples must include some young growth stands. Reasonably undisturbed stands can still be found in the mixed conifer zone, but sampling only in these spots would bias the samples toward poorer site qualities.

Selective disturbance of these forests started long ago. Over most of the mixed conifer forest, shake cutters high-graded the truly large pines in the last

century. More recently, the largest pines have been selectively cut from the eastside forests because of their high insect risk.

I reduced the variation in soil forming factors between plots as much as possible by sampling only upland, volcanic soils. The mineralogical similarities in the basaltic and andesitic parent materials should have lessened the nutrient differences. Only plot 22 on the acidic rock dacite, departed from the basic igneous pattern in parent material (*table 1*).

The volcanic origin of the landscape also simplified the topographic situation. Only four plots were steep enough so that slope *per se* affected soil moisture conditions. The other plots were on level flows or on gently sloping benches along broad ridges. Lower slopes where downhill movement of water and nutrients might be a significant factor were avoided. All plots drained well. The minimal slope differences between plots strengthened the correlation between elevation and temperature.

The Soil-Vegetation Survey helped stratify the more important soils (*table 1*). First, I sampled Aiken (clay loam/clay), Cohasset (loam/clay loam), and Windy (sandy loam) soil series. Within each

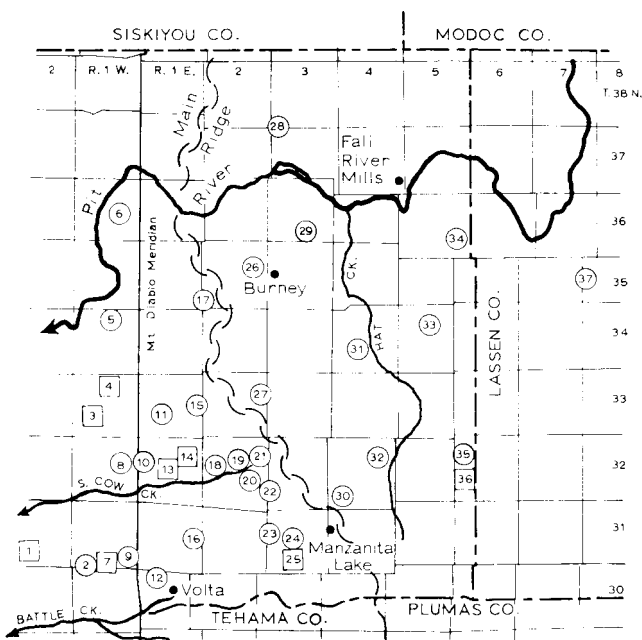


Figure 2.—Sample plots within the study area were numbered from west to east. Plots 1 to 25 face the Sacramento Valley, and are west of the main ridge. Plots 26 to 37 are east of the ridge in the central Pit River drainage. Circles indicate the regular plots; squares, the supplementary plots.

of these groups a broad range of site qualities was selected. Then some of the more localized soil situations were sampled for contrast with general conditions.

### Moisture Sampling

Early in the project, a variety of types of soil samples were gathered. Whenever possible, I took material from the 10, 20, 40, 80, 120, 160, and 200 cm. depths. Estimates of soil depth and rock volume (table 1) were based on these samples. In the final moisture survey, only the 40 and 80 cm. depths were sampled.

Because of the difficulty in estimating volumes, I abandoned the use of any storage capacity method of evaluating soil moisture such as Waring had used. Instead, the samples were taken so that field soil moisture contents could be converted directly into tension figures.

### Field Soil Moisture Samples

For the main survey I dug three separate pits on each sampling date. To have some control over direct vegetational effects on moisture depletion, I dug each pit in a zone of intense root activity. All pits started in litter covered soil beneath the central portion of a tree crown. Thus, even though stands of different densities and degrees of disturbance had to be used, the samples should have some comparability in evapotranspirational stress from the trees above them. No samples came from openings where root distribution might have been low.

Samples came from fixed depths as a matter of convenience. Horizon development is usually not abrupt in these soils. At a given depth, I took only one sample (5 cm. thick) per pit. Earlier experience showed that duplicate samples from the same depth in one pit often agreed within tenths of a percent or less in dry weight moisture content. In some cases there were too many rocks and insufficient time to dig all three pits to maximum depths.

The fresh material was passed quickly through a 5-mm. screen into a metal can. The entire process of removing the sample and screening it required only a few seconds. Mixing of drier soil into—or evaporation from—the sample was negligible.

The use of a 5-mm. soil fraction here departs from the traditional 2-mm. fraction, but follows the lead of McMinn (1960), Cleary,<sup>5</sup> and others. In rocky forest soils this coarser fraction preserves a more natural structure and rock particle content. In soils like the Aiken series, field screening to 2 mm. removes a large portion of stable aggregates. Since a coarser fraction was used, the results may not be strictly comparable with conventional data, but they may be more ecologically useful. The sample cans, which held about 100 grams of dry soil, were sealed with masking tape and weighed within 4 to 8 hours then oven-dried at 105° C. for 24 hours.

I collected the first series of moisture samples on

<sup>5</sup>Cleary, B. D. *Op cit.*



Table 1.--Selected environmental characteristics at sample plots,  
Shasta County, California

Plot No.	Elevation	Precipitation <sup>1</sup>	Parent material <sup>2</sup>	Soil series	Soil depth <sup>3</sup>	Rock volume <sup>4</sup>
	M.	Cm.			Cm.	Pct.
1	396	84	Pleist. basalt	Guenoc (Aiken-like)	75	25-50
2	563	86	Pleist.	Aiken	200+	5-10
3	640	107	Plio.	Aiken	100	10-15
4	762	114	Plio.	Aiken	100+	5-10
5	747	165	Jura-Triois. meta-basalt	Aiken	200	0-5
6	884	173	Plio. basalt	Aiken	200+	0-5
7	663	91	Pleist. basalt	Aiken	100	10-15
8	671	102	Pleist. basalt	Aiken	100+	5-10
9	823	97	Pleist. basalt	Aiken	100+	10-15
10	747	107	Pleist. basalt	Aiken	200	0-5
11	1,097	127	Plio. basalt	Cohasset	100+	5-10
12	1,082	102	Pleist. basalt	Cohasset	200	0-5
13	838	114	Pleist. Basalt	Aiken	100	10-15
14	960	127	Plio. andesite	Cohasset	200	0-5
15	1,396	152	Pleist. andesite	Cohasset	150	25-50
16	1,189	109	Pleist. basalt	McCarthy (Windy-like)	100	25-50
17	1,295	165	Plio. andesite	Windy (Cohasset)	100	25-50
18	1,067	132	Plio. tuff- breccia	Lyonsville (Cohasset-like)	200	5-10
19	1,417	140	Pleist. andesite	Cohasset	250+	25-50
20	1,859	147	Plio. andesite	Windy (Lytton-like)	100+	50-75
21	1,676	147	Plio. andesite	Cohasset	100+	25-50
22	1,798	147	Plio. dacite	Jiggs	100	25-50
23	1,341	119	Plio. basalt	Windy (Cohasset)	100+	25-50
24	1,509	127	Plio. andesite	Windy (Shasta-like)	100	25-50
25	1,509	12	Pleist. andesite	Windy	100	25-50
26	1,052	89	Plio. basalt	Cohasset	150	5-10
27	1,524	152	Pleist. basalt	Windy	100	25-50
28	1,005	97	Miocene basal	Aiken	100+	5-10
29	968	45	Pleis. Basalt	Aiken-like (Tournquist)	100+	5-10
30	1,646	112	Pleist. basalt	Windy	100	50-75
31	1,219	64	Plio. basalt	Cohasset	50+	25-50
32	1,448	81	Pleist. basalt	Windy	100	25-50
33	1,326	46	Pleist. basalt	Aiken-like (Tournquist)	100	10-20
34	1,189	41	Recent basaltic cinders	Cone-like	50+	50-75
35	1,676	64	Pleist. basalt	Windy	150+	10-20
36	1,695	71	Pleist. basalt	Windy-like	100	25-50
37	1,326	38	Plio. basalt	Wagontire (Martineck- like)	40	75-100

<sup>1</sup>Meal annual precipitation estimated from plate 4, Shasta County Investigation. Calif. Dep. Water Resources Bull. 22, 239 pp., illus. 1964.

<sup>2</sup>Geologic ages from Lydon, P. A. Gay, T. E., Jr., and Jennings, C. W. (compilers). Westwood sheet, geologic map of California. Calif. Div. Mines & Geology. 1960.

<sup>3</sup>Minimum depths estimated from about 15 observations per plot for the regular plots.

<sup>4</sup>Rock volume (>5 mm.) estimated from all plot digging experience.

the regular plots in late September 1963. Lower elevation plots were visited first. Sampling of all plots required about 2 weeks. In 1964 the regular plots were sampled in May, August, and September. In 1965, I took only a late September series.

#### Soil Moisture Tension Curves

Pressure plate equipment and techniques were used to determine soil moisture contents of each sample at specific soil moisture tensions. In view of the wide variations in the field, reproducibility

of laboratory results offered no problems. Determined moisture contents of duplicate plot soils agreed within 1 percent both within a given pressure plate run, and between separate runs at the same tension. The only technique problem encountered during the tension work involved samples from shallow depths in Windy-like soils. They often would not "wet" unless they were completely saturated with detergent, and the results were sometimes erratic.

Soil moisture contents at the 0.3 and 15 atmosphere tensions at all depths were surveyed to estimate the range of moisture availability. The 15-atmosphere moisture contents are used as an arbitrary drought standard. I am not implying that the woody species, particularly the conifers, "wilt" when the average soil moisture tension level reaches 15 atmospheres. Different physiological processes are limited at different soil moisture tensions (Gardner and Nieman 1964).

Individual soil moisture tension curves were derived from 0.3, 1, 3, 5, 10, and 15 atmosphere data for both the 40 and 80 cm. depth samples at every plot (*fig. 3*). Field moisture contents were converted to tension figures from these curves.

### **Vegetation Sampling**

In 1963 I began listing recognizable plant species on the plots. The few mosses and lichens present were not identified. Floristic observations continued for 3 years. Herbarium specimens of species listed were filed at Redding. The plant names follow the usage of Munz (1959) unless authors are listed.

Quantitative study of the vegetation started in 1965. I sampled the lower elevation plots first. About 2 months were required to cover all localities, and all plots were not sampled in closely com-

parable seasonal stages. However, almost all known perennial species were recognized and appeared in the frequency quadrats. Details of the sampling design at a given locality are:

<i>Unit</i>	<i>Size</i>	<i>Type of Data</i>
one "plot"	0.81 hectare (2 acres)	list of species on plot
five "strips" within plot	total of 0.20 hectare chains, 0.5 chains apart)	basal area of trees (each quadrat, frequency of strips)
Fifty "quadrats" on centerline of strips	total of 0.02 hectare (each 1 milacre, 0.5 chains apart)	list of species on quadrats, fre- quency of herbs, and tree seedling

The d.b.h. of all living trees (over 5 cm.) were measured. In logged plots d.b.h. estimates were added for all stumps.

I took site index measurements in all plots where any trees approaching the required standards could be found. In mixed conifer stands heights of the tallest residual old-growth trees of any species were sought (Dunning 1942). In second-growth pine communities, I used dominant trees in the more even-aged groups (Arvanitis, Lindquist, and Palley 1964).

## **Results and Discussion**

### **Climatic Context**

Data collected by weather stations in and around study area are adequate to describe general precipitation conditions. Long-term temperature records, however, are limited. Evapotranspiration data, calculated from published temperature records, would not help in making comparisons between my plots.

Only light, widely scattered thunder showers fell during the summer of 1963 (*fig. 4*). After this "normal" summer, field samples taken in September should have given reasonable estimates of minimum soil moisture conditions. Fall storms started just as the last samples were collected.

The winter of 1964 was relatively dry. A few late spring storms kept the growing season from starting in an exceptionally dry state. July and August were typically rainless. However, one "unseasonal" storm passed over northern California early in September (*fig. 4*). This rain added available moisture to surface soil layers at some plots,

but it probably had little effect on the 40 and 80 cm. depth samples. Again, the September samples should have given a good estimate of minimum field moisture conditions.

Growing conditions were unusually favorable in 1965. Spring rains were well timed. A series of "unseasonal" general storms over the entire region and heavy showers over the higher country added some available moisture to all plots during the summer (*fig. 4*). This "wet" season contrasted with the two preceding summers.

Temperatures were slightly below long-term normals for most Shasta County stations during all three summers. More above normal readings occurred in 1964 than in the other two years; however, it was not a really "hot" year by local standards.

During the growing season, mean monthly temperatures may vary at least 15° F. between different plots within the transect. For example, mean

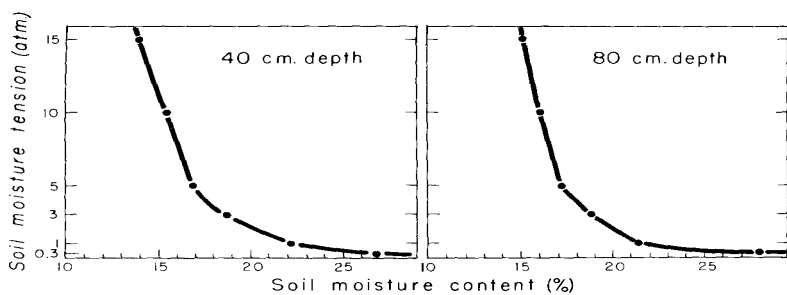


Figure 3.—Soil moisture tension curves for the Aiken soil sample at plot 2. Similar curves were made for 40 and 80 cm. depth samples at all plots.

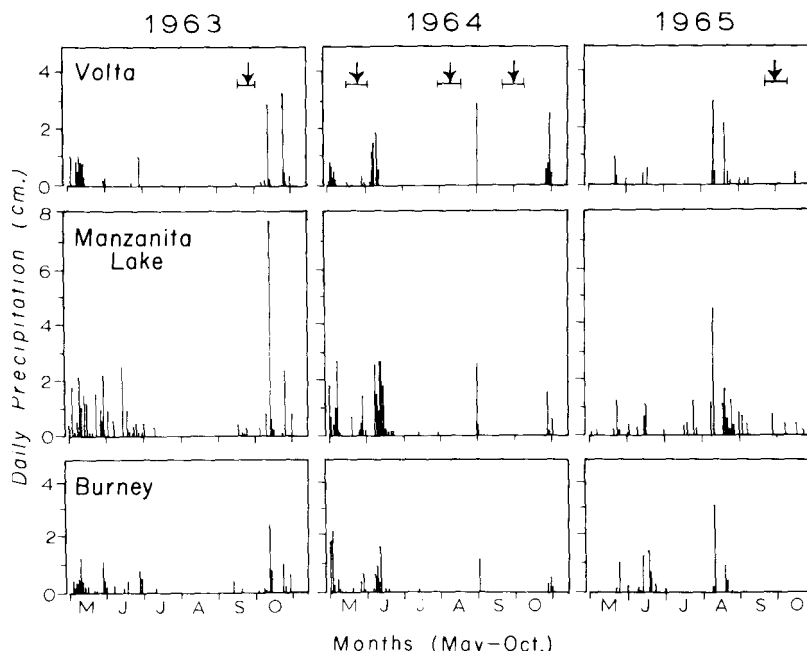


Figure 4.—Summer rainfall patterns at three stations within the study area during the 3 years that soil moisture samples were collected. Field collection periods are indicated below the arrows. Weather station locations are shown in fig. 2.

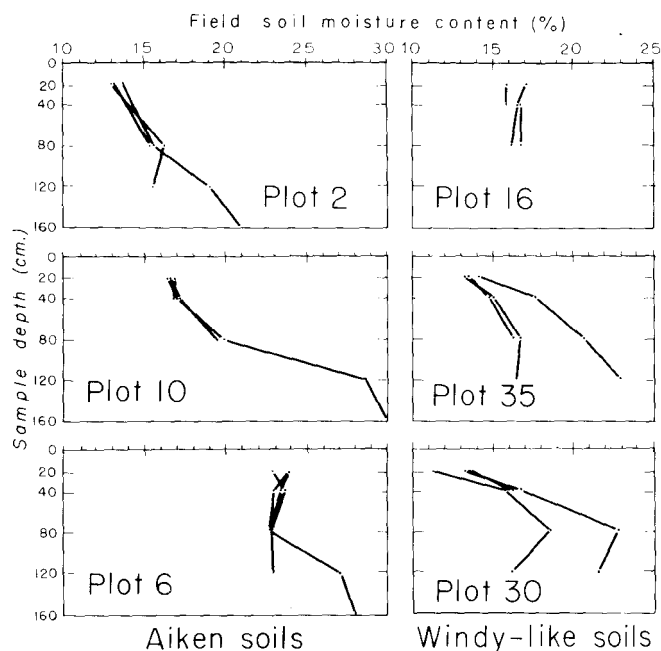


Figure 5.—September, 1964 soil moisture content as a function of sample depth in each of three pits at three plots with deep, non-rocky, Aiken soils and three plots with rocky, Windy-like soils.

monthly temperatures in 1964 were:

	June	July	August
	<i>(degrees)</i>		
Manzanita Lake	52	63	62
Volta	67	76	76

Manzanita Lake is representative of some higher elevation habitats in the central and eastern portions of the transect. A few of the higher plots may be cooler.

Volta data reflect the great evaporative stress in the lower elevation westside plots where temperatures may rise into the 90's every day for months on end. Maximum temperature at Volta in 1964 was 103°F.—only 10° below the Sacramento Valley high for the same date.

Since no pertinent temperature records were available, moisture data developed below were plotted against elevations for discussion purposes. Temperatures are related to elevation but use of elevation may obscure some broad geographic trends. For example, plots east of the main ridge have much cooler nights during the growing season. Eastside plots also have markedly lower winter minimums.

### **Soil Moisture Patterns**

#### **Within-Plot Variation**

Variability in moisture regimes between pits on a given plot was small in deep, non-rocky soils like the Aiken series (*fig. 5*). Replications at depths down to 80 cm. usually fell within a range of 1-percent moisture content. Greater uniformity is unlikely in California forest soils.

Deviations between the deeper Aiken samples from adjacent pits may be due to the fixed collection depths. The moist 120-cm. samples at plots 2 and 6 (*fig. 5*) came from well developed B horizons. The drier 120-cm. samples at these plots probably came from spots where the clay horizon was a little deeper than 120 cm. The differences may also be partly due to rooting patterns. The denser clay horizons may restrict root growth in places, resulting in less moisture depletion and higher moisture contents.

Rocky, Windy-like soils gave more variable results at all depths (*fig. 5*). The 2 to 5 percent differences between samples at given depths may reflect both a real increase in soil variability and difficulty in getting comparable samples.

Better estimates of root distribution and profile development would have been desirable at some plots. A larger number of pits per plot would have

been helpful in the rocky habitats. But for this type of survey, the sampling methods seem adequate to characterize soil moisture regimes on the plots for the sampling dates.

#### **Estimating Soil Moisture Availability**

Absolute moisture contents, as illustrated in *fig. 5*, have little ecological meaning when different soil textures are involved. Similar soil moisture contents can be associated with vastly different vegetation types. An Aiken sample could have more water in it at 15 atmospheres tension than a Windy sample does at 0.3 atmosphere tension.

If average field moisture contents (*fig. 5*) are placed in the context of the range of moisture availability—the range between 0.3 and 15 atmosphere moisture contents—the ecological differences between these plots becomes apparent (*fig. 6*). For example, the Aiken, clay loam samples down to 120 cm. depth (plot 2) were near the 15 atmosphere moisture content in September. This plot then was under high drought stress. In the Windy, sandy loam sample (plot 30) (below 20 cm. depth) moisture contents were much higher than the 15 atmosphere level. This plot was under much less drought stress in September.

Ten-cm. depth samples dried out so early in the season that they had no value in comparing moisture regimes. The 20-cm. depth samples began to show differential results but still dried out quickly. The possibility that such shallow layers would be wetted by summer showers was also great. Data from the deepest samples were either incomplete or so variable that they are useful only in parts of the study area. So, I finally chose the 40- and 80-cm. depth samples to characterize moisture conditions. By using these two intermediate points I got some measure of moisture relations in the upper zones where most of the nutrients are concentrated. I also sampled the fringes of deeper zones important for storage of water late in the season.

All field moisture contents at these two depths were converted into tensions using curves similar to those in *fig. 3*. The seasonal trend during 1964 followed the expected course. May samples were near field capacity. At lower elevations the August data approached or equaled the September levels. Higher elevation plots had not reached maximum soil moisture tensions by August. Representative data comparing the maximum tensions during 3 successive years appear in *table 2*. Considering all of the sampling difficulties, the similarities in re-

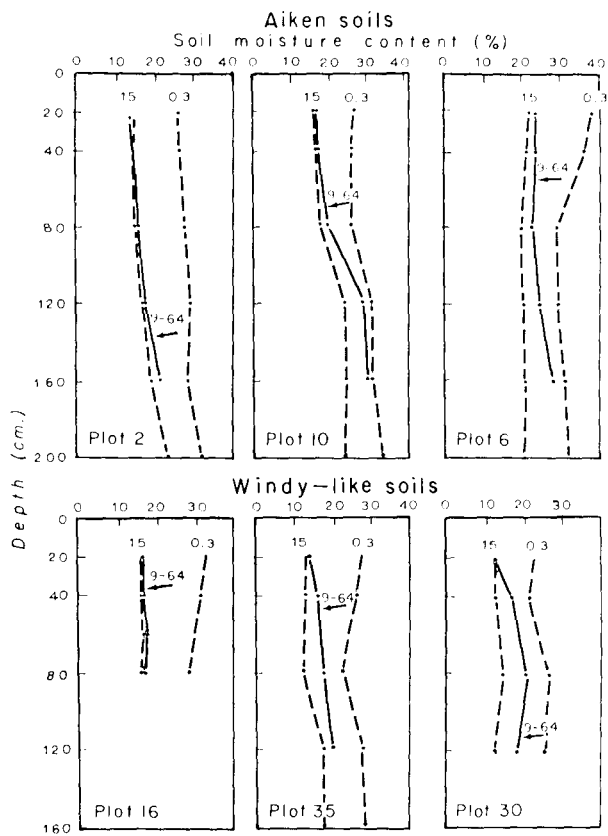


Figure 6.—The relationship of 1964 minimum field moisture contents and the available moisture range in three representative Aiken and three Windy-like soils.

Table 2.--Maximum soil moisture tensions within three soil groups, sampled at two depths for 3 successive years, Shasta County, California

AIKEN SOILS						
Plot number	40-cm. depth			80-cm. depth		
	Sept. 1963	Sept. 1964	Sept. 1965	Sept. 1963	Sept. 1964	Sept. 1965
	Atm.			Atm.		
2	17.0	17.0	13.0	16.0	13.0	16.0
10	8.0	11.5	7.0	1.5	3.0	10.0
28	4.0	11.0	6.0	1.0	4.0	3.5
5	7.0	7.5	8.0	4.5	3.0	4.0
6	7.0	5.0	5.0	3.0	3.0	4.0
COHASSET-LIKE SOILS						
31	17.0	13.0	17.0	10.0	7.5	15.0
11	8.5	7.5	6.0	2.5	3.5	3.0
26	7.5	7.5	7.5	4.5	1.0	4.5
19	4.5	3.5	3.5	2.0	2.0	.5
15	2.5	2.5	2.0	2.5	2.0	2.0
WINDY-LIKE SOILS						
16	10.0	12.0	12.0	8.0	10.0	15.0
35	9.5	6.0	2.5	3.0	1.5	1.5
24	3.5	3.5	2.5	1.0	2.0	2.0
20	2.0	3.5	3.5	1.0	1.0	1.0
30	1.0	2.0	1.0	.3	1.0	.5

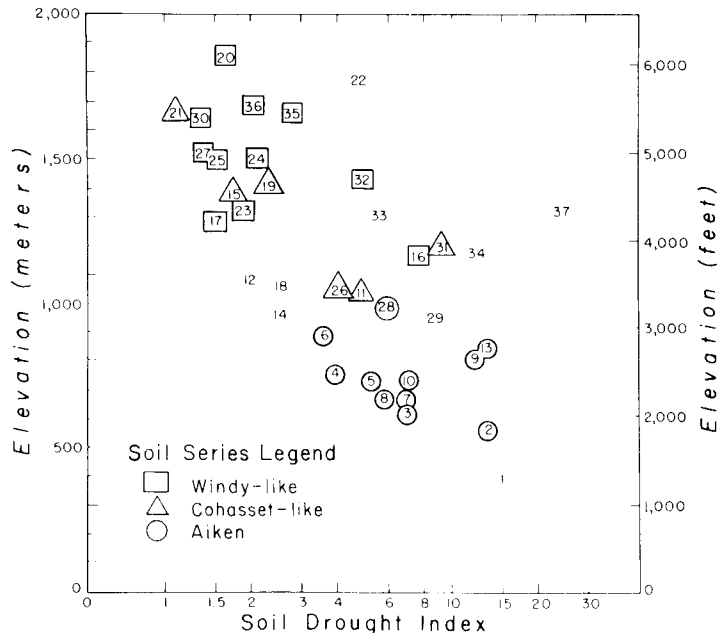


Figure 7.-The relationships of three groups of soil series to elevation and SDI gradients. Numbers refer to the position of regular and supplementary plots, plots without symbols are not on these major series.

Table 3.--Four soil moisture tension values available for each regular plot and their average Soil Drought Index

Plot number	August 1964		September 1964		Soil Drought Index
	40 cm.	80 cm.	40 cm.	80 cm.	
21	1.5	0.2	1.5	1.0	1.1
30	1.5	.5	2.0	1.0	1.3
27	1.5	.7	2.0	1.5	1.4
17	1.5	.2	3.5	.8	1.5
20	1.5	.5	3.5	1.0	1.6
15	1.5	.9	2.5	2.0	1.7
23	2.5	1.0	2.0	1.5	1.8
12	3.0	.7	3.0	1.0	1.9
24	2.5	.5	3.5	2.0	2.1
19	2.5	.8	3.5	2.0	2.2
18	2.0	.8	5.0	2.0	2.5
35	3.0	.6	6.0	1.5	2.8
6	4.0	2.0	5.0	3.5	3.6
26	7.0	.8	7.5	1.0	4.1
22	3.5	3.0	6.5	6.0	4.8
11	5.5	3.0	7.5	3.5	4.9
32	5.5	2.5	7.0	4.5	4.9
5	7.5	2.5	7.5	3.0	5.1
33	5.0	3.5	10.0	3.5	5.5
8	5.0	.8	14.5	3.0	5.8
28	7.0	1.5	11.0	4.0	5.9
10	10.5	3.0	11.5	3.0	7.0
16	4.5	4.0	12.0	10.0	7.6
31	13.0	2.5	13.0	7.5	9.0
29	10.0	2.5	15.0	8.5	9.0
9	9.0	11.0	15.0	13.0	12.0
34	6.8	8.0	20.0	14.0	12.0
2	13.0	10.0	17.0	13.0	13.3
37	25+	(1/)	25+	(1/)	25+

<sup>1</sup>Hardpan.

sults year after year at many plots are encouraging. These data generally appear to rank the plots into reasonable ecological patterns.

### Soil Drought Index

Which of the tension data would best express the drought potential of all plots? The 1965 data were not used in the initial ranking of the plots because some plots may not have dried out to normal drought levels during the “wet” season. The 1963 data estimated maximum tensions but were less complete than those of 1964. Thus, the August and September data from 1964 seemed the most appropriate to use.

Combining depth and season factors into one index posed the next problem. Should 80 cm. samples be given more weight than the shallower samples that dried out more quickly? Or were September values during a semi-dormant vegetative period less important than earlier values when some plants were still actively growing?

Several schemes were tried—ranking by August data, ranking by September data, ranking by each depth, etc. All gave similar results. Finally the four tension figures from every plot were arithmetically averaged into a single Soil Drought Index (*table 3*). This method gave a gradient that appeared ecologically meaningful. In a crude way the “average” value represents the soil moisture tension at the 60 cm. depth early in September. The physical meaning of this average should not be pushed too far; I would emphasize the *relative value* of these Soil Drought Index (SDI) numbers.

After the SDI values were established for all regular plots, tentative SDI values were estimated for the supplementary plots from all available soil moisture evidence. The discussion below is based on findings from the regular plots, but the supplementary plot data contribute to the over-all patterns and are included in some figures.

My approach gives no information on amounts of moisture at any plot. It assumes that as long as a portion of the rooting zone in one plot is at a lower average tension than that of a second plot, the plot with the lower tension is moister. For example, a large volume of soil was available to a tree on plot 2, but most of this soil was near the wilting point (*fig. 6*). A smaller volume of soil was available to a tree on the rocky soil of plot 30; yet, some moisture was still available at the date of sampling (*fig. 6*). The quantity of usable water in the coarse textured soil of plot 30 may be small, but in relative terms it is the moister habitat.

Each of the major soil series embraced a broad range of SDI values. When these values were plotted against elevation, however, a reasonable pattern formed (*fig. 7*). The positions of the plots in this moisture and elevation context are consistent with the soil development trends discussed by Zinke and Colwell (1965).

The overlap of Cohasset and Windy groups may be partly due to the difficulty in digging down between the rocks to check the development of the B horizon. For example, plots 17 and 23 might be classed as Cohasset rather than Windy after closer study.

The droughty nature of the low elevation Windy-like soil (plot 16) is obvious in this type of presentation (*fig. 7*). Morphologically this soil resembles the high elevation Windy soils. But it is located at a low enough elevation so that the high evapotranspirational stress uses up its limited storage capacity (*fig. 6*). Interestingly, one of the few areas within the middle elevation mixed conifer forest in Shasta County where a serious brush competition problem exists is next to plot 16. There are aggressive brushfields on the Windy-like soils but few brushfields on the surrounding Cohasset soils.

In contrast, plot 24's extremely low field soil moisture contents (10 percent in September) are associated with relatively moist conditions. Although this sandy loam soil also has a small storage capacity, its cool physiographic setting keeps it from completely drying out.

Plot 22 is displaced from the Windy soil group because of the dacite parent material (*fig. 7*). Its sandy, gravelly profile is much droughtier than Windy soils at the same elevation. The very rocky soil on recent cinders at plot 34 is also droughtier than the adjacent zonal soils. Plot 37 is an extremely unfavorable habitat for forest trees with its shallow, rocky soil over a hardpan.

Three other plots are closely related to the Aiken group (*fig. 7*). The clay loam at plot 1 is intermediate between the Guenoc and Aiken series. Soils at the eastside plots 29 and 33 have been tentatively called Tournquist series, but they might be lumped into the Aiken series before their classification is settled.

## **Vegetation Patterns**

### **Community Classification**

Low elevation pine communities, middle elevation mixed conifer stands, and pure fir types at higher elevation make up the commercial forests of the Sierra Nevada. This sequence continues north-

ward from the Sierra Nevada granitic region onto the Cascade volcanic parent materials. A few gross features of this forest zonation will be considered before presenting more specific vegetation data.

Within the study area, the westside pine zone is relatively narrow. Near plots 2, 7, and 9 it extends about 6 km. through an elevational range of 450 m. (fig. 2). Often the pine stands appear more as ecotones between the foothill woodland and mixed conifer forest than as important independent communities.

Well developed mixed conifer communities continue eastward above the pine zone for over 30 km. These forests usually have five major conifers and one oak species scrambled together. On gravelly benches or south facing slopes pines and oaks are conspicuous in the mixture. On higher ridges and northern aspects, firs dominate.

East of the main mixed conifer zone a mosaic of poorly developed mixed stands (on slopes) and pine stands (on flats) begins. On the Modoc Plateau these eastside pine stands become extensive, and only the higher ridges support mixed forests.

When these communities are studied only in terms of soil drought conditions, confusion results.

For example, some "droughty" looking eastside pine stands have more moisture available than some well-developed mixed conifer stands. If the relative dominance of tree species is plotted against both elevation and SDI gradients, however, a better picture of this shifting forest composition emerges (fig. 8). The plots fall into groups with reasonable floristic and ecological unity. I have placed these groups in the context of Munz's (1959) classification of California vegetation. The relationship of such groups to conventional forest cover types and other vegetation units is shown in table 4.

Most of my plots fall within the yellow pine forest community type of Munz. Since the term "yellow pine" has a confusing history of forestry uses, I prefer to change "yellow pine" to "mixed conifer forests." Subdivisions within this type, however, should be recognized. Within the Shasta County mixed conifer forest I have suggested four different dominance phases (fig. 8). The boundaries between them are vague, and they represent four common conditions within a continuous array of variation. Each phase might contain several associations in phytosociological terms; in other parts

Table 4.--Relationship between plant community types in the study area to other vegetation units

Plant community types	Forest cover types <sup>1</sup>	Related vegetation units from other studies
Red fir forest <sup>2</sup>	Red fir (207)	Red fir forest <sup>3</sup>
Mixed conifer-forest: white fir phase mixed phase	White fir (211) Ponderosa pine-sugar pine-fir(293) Ponderosa pine- Douglas-fir (244)	<i>Abies-Ceanothus</i> <sup>4</sup>
eastside pine phase	Interior ponderosa pine (237) Jeffrey pine (247)	<i>Pinus-Purshia</i> <sup>4</sup> <i>Pinus-Purshia-Festuca</i> <sup>4</sup> <i>Pinus-Purshia-Arctostaphy-</i> <i>los</i> <sup>4</sup>
westside pine phase	Pacific ponderosa pine (245) California black oak (246)	
Foothill woodland: savanna phase chaparral phase	Digger pine-oak (250)	
Northern juniper wood- land	Western juniper (238)	

<sup>1</sup>Names and numbers refer to type descriptions (Soc. Amer. Foresters 1954).

<sup>2</sup>No plots actually fell within this type, which occurs on highest ridges just above the white fir phase.

<sup>3</sup>Oosting and Billings (1943).

<sup>4</sup>Dyrness and Youngberg(1966).



Table 5.--Basal area as a measure of tree species dominance along the Soil Drought Index gradient across the study area

Species	Westside plots <sup>1,2</sup>																	
	2	9	16	10	8	5	11	22	6	18	19	12	23	15	20	17	21	
	13.3	12.0	7.6	7.0	5.8	5.1	4.9	4.8	3.6	2.5	2.2	1.9	1.8	1.7	1.6	1.5	1.1	
	Square m./hectare																	
<i>Pinus monticola</i>	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	(4/)	
<i>Abies magnifica</i>	--	--	--	--	--	--	--	1.1	--	--	--	--	--	--	--	--	(4/)	
<i>Abies concolor</i>	--	--	3.0	(4/)	--	2.6	6.4	5.7	4.1	2.3	14.2	3.7	54.9	10.8	5.7	25.3	76.9	
<i>Pinus lambertiana</i>	--	--	(4/)	(4/)	--	(4/)	5.7	4.6	(4/)	--	13.1	(4/)	8.7	34.0	(4/)	3.2	20.9	
<i>Pseudotsuga menziesii</i>	--	--	(4/)	(4/)	--	15.8	8.3	--	8.3	1.5	16.8	(4/)	12.6	2.1	--	23.4	(4/)	
<i>Libocedrus decurrens</i>	--	--	7.8	20.7	3.7	12.9	10.3	--	7.3	13.1	10.2	18.8	7.3	22.3	.2	8.7	.2	
<i>Pinus ponderosa</i>	(4/)	2.3	3.7	34.4	14.0	7.3	19.1	--	8.9	3.2	14.2	14.2	(4/)	1.6	--	.7	3.4	
<i>Quercus kelloggii</i>	11.7	15.8	7.3	11.5	11.0	9.2	2.3	--	6.0	3.0	1.1	5.7	.9	.7	.5	.9	--	
<i>Quercus garryana</i>	--	10.8	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
<i>Pinus jeffreyi</i>	--	--	--	--	--	--	--	--	--	--	--	--	--	--	3.4	--	3.4	
<i>Pinus sabiniana</i>	2.5	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
<i>Juniperus occidentalis</i>	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
<b>Total</b>	<b>14.2</b>	<b>28.9</b>	<b>21.8</b>	<b>66.6</b>	<b>28.7</b>	<b>47.8</b>	<b>52.1</b>	<b>11.9</b>	<b>34.6</b>	<b>33.1</b>	<b>70.0</b>	<b>42.4</b>	<b>84.4</b>	<b>71.5</b>	<b>9.8</b>	<b>62.2</b>	<b>104.8</b>	
	Eastside plots <sup>1,3</sup>																	
	30	27	35	26	32	33	28	31	29	34	37							
	1.3	1.4	2.8	4.1	4.9	5.5	5.9	9.0	9.0	12.0	25+							
	Square m./hectare																	
<i>Pinus monticola</i>	--	--	--	--	--	--	--	--	--	--	--							
<i>Abies magnifica</i>	--	--	--	--	--	--	--	--	--	--	--							
<i>Abies concolor</i>	49.1	24.8	(4/)	1.1	(4/)	--	--	1.4	--	--	--							
<i>Pinus lambertiana</i>	--	(4/)	--	(4/)	--	--	(4/)	3.0	(4/)	--	--							
<i>Pseudotsuga menziesii</i>	--	--	--	6.7	--	--	7.3	.5	--	--	--							
<i>Libocedrus decurrens</i>	.2	.2	--	16.5	--	--	6.9	7.1	--	--	--							
<i>Pinus ponderosa</i>	27.6	27.6	34.7	14.5	6.0	17.4	23.9	11.5	17.2	13.5	--							
<i>Quercus kelloggii</i>	--	--	--	13.4	--	--	1.4	2.1	2.3	--	--							
<i>Quercus garryana</i>	--	--	--	--	--	--	--	--	5.3	--	--							
<i>Pinus jeffreyi</i>	24.3	--	8.5	(4/)	30.3	(4/)	--	--	--	.7	1.1							
<i>Pinus sabiniana</i>	--	--	--	--	--	--	--	--	--	--	--							
<i>Juniperus occidentalis</i>	--	--	--	--	--	1.8	--	--	--	--	6.4							
<b>Total</b>	<b>73.4</b>	<b>52.6</b>	<b>43.2</b>	<b>52.2</b>	<b>36.3</b>	<b>19.7</b>	<b>39.5</b>	<b>25.6</b>	<b>24.8</b>	<b>14.2</b>	<b>7.5</b>							

<sup>1</sup>All regular plots listed except number 24 which is in a brushfield and had no tree basal area.

<sup>2</sup>Plots ranked along decreasing drought stress up the west slope of the Cascade ridge, SDI listed under each plot number.

<sup>3</sup>Plots ranked along increasing drought stress up the east slope of the Cascade ridge, SDI listed under each plot number.

<sup>4</sup>Species present on plot but had less than 0.1 m.<sup>2</sup>/h. on cruise strips.

of California, additional phases might be necessary.

Figure 8 is helpful in showing the central position of the mixed conifer forest in Sierra-Cascade forest vegetation. It also reveals the interrelationships of the four phases within the local mixed conifer forest.

In other regions it might be better to emphasize the separateness of the pine types from the mixed type. Whittaker viewed his pine woodlands and montane forest as distinct formations. I would like to stress their intermediate character—westside pine stands joining the foothill woodland to the mixed conifer forest, and eastside pine stands merging the juniper woodland to the mixed conifer forest (fig. 8).

In Shasta County the westside and eastside forests are less isolated geographically than along most of the Sierra Nevada-Cascade axis (Griffin 1966). Plots along the Pit River canyon and lower portions of the Burney basin would yield a series of intermediate environments and intermediate vegetation types. The manner in which the two pine phases fit around the mixed phase reflects this situation (fig. 8).

### Relative Tree Dominance

All plots in the central portion of the transect now clearly have mixed conifer stands (table 5). The tree reproduction data suggest that this condition will continue although the proportion of different species may change. Thus, *Libocedrus decurrens* comprised about one third of the basal area in plot 31, but it has well established reproduction on some 90 percent of the area. *Libocedrus* will be more important in the next stand.

For practical purposes, the westside pine stands are climax communities. Successional trends toward mixed conditions, however, are not hard to find in sheltered spots. Thus, plot 10 at only 747 m. elevation is just above the foothill woodland. Yet, all of the mixed conifer species have a couple of saplings established (table 5).

Plot 30 illustrates the upper end of this sequence where the trend is toward pure fir stands. Although it has one third of its basal area in *Pinus jeffereyi* now, the pine will become a minor component in the fir stand with time.

Plots 32 and 35 both show the tendency for many eastside pine stands to have a sprinkling of understory firs.

All of the overstory tree species had broad tolerances to moisture conditions. *Pinus ponderosa* and *Quercus kelloggii* are good example (fig. 9).

They both formed larger percentages of the stand on drier plots but had no sharp moisture preferences. *Abies concolor* showed a greater dominance on moister plots (fig. 9).

*Pinus jeffreyi* managed to grow on both the wettest and driest plots. Although my sampling is too limited to be conclusive, *P. jeffreyi* appears to have a bimodal distribution (fig. 9). It grows on dry, eastside flats and on moist, higher slopes on both sides of the main ridge. These two kinds of *P. jeffreyi* habitats are usually separated by a distinct zone of mixed conifer forest.

Theoretically, physiological ecotypes are to be expected within such widely distributed tree species. Unfortunately, there is no convenient way to recognize them. No obvious morphological differences are revealed as they grow in the field.

Few understory trees appear on the plots, and none contributed to the basal area data. Small *Cornus nuttallii* trees were present on seven plots. *Taxus brevifolia* and *Acer circinatum* were the only trees with conspicuously narrow moisture tolerances. In Shasta County they are largely riparian species and grow only sparingly on uplands. *Taxus* was present on plots 17 and 18. Only plot 17 had the maple. If I had included higher elevation stands north of the Pit River in the transect, these understory trees would have assumed greater importance.

*Quercus chrysolepis* played a minor role in the understory. On steep, rocky slopes large trees form an important part of the forest, often in company with *Pseudotsuga menziesii* (see type 249, Soc. Amer. Foresters 1954). On the study plots *Q. chrysolepis* appeared only as scattered shrubs or small trees.

### Site Quality

Neither the vegetation units outlined above nor their related site quality classes coincide very well with any soil series. Most of the fir stands are on Windy-like soils; yet, these soils include some of the highest quality mixed conifer stands as well as extensive non-timbered high elevation brushfields. There may be a better correspondence of mixed conifer stands with Cohasset soils. Most of the westside pine stands are on Aiken soils, but these soils stretch from the upper fringes of non-commercial foothill woodland to productive mixed conifer stands.

This range of variation in vegetation types and site qualities within the Aiken soil series is shown in greater detail in table 6. Although there are difficulties in finding appropriate site measurement

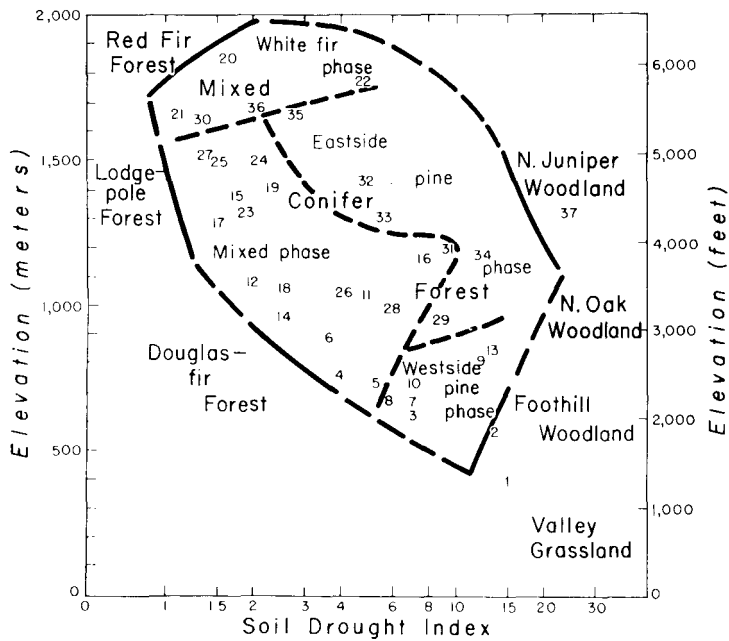


Figure 8.—The relationship of plant community types (Munz 1959) to elevation and SDI gradients. Numbers refer to positions of regular and supplementary plots.

Figure 9.—Relative dominance (basal area of given species as a percentage of total basal area on plot) of selected trees species along the SDI gradient. Numbers refer to positions of individual plots.

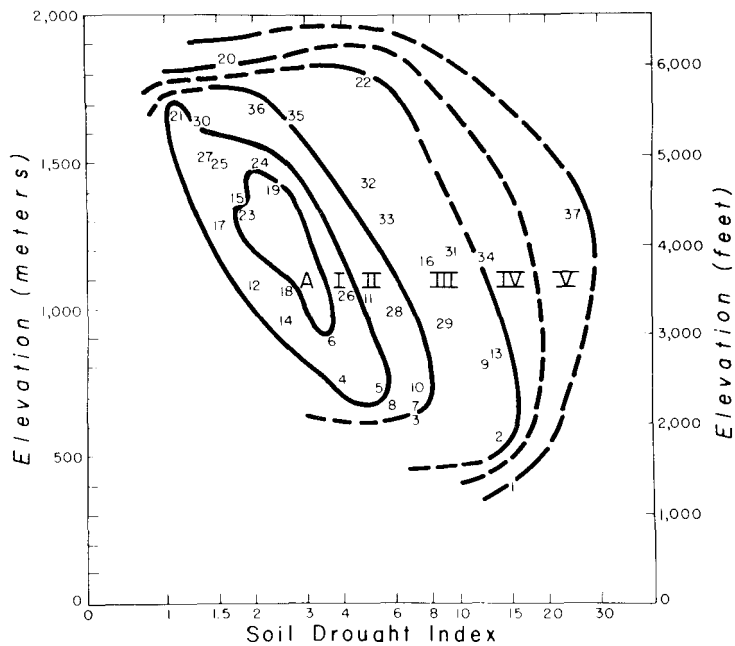
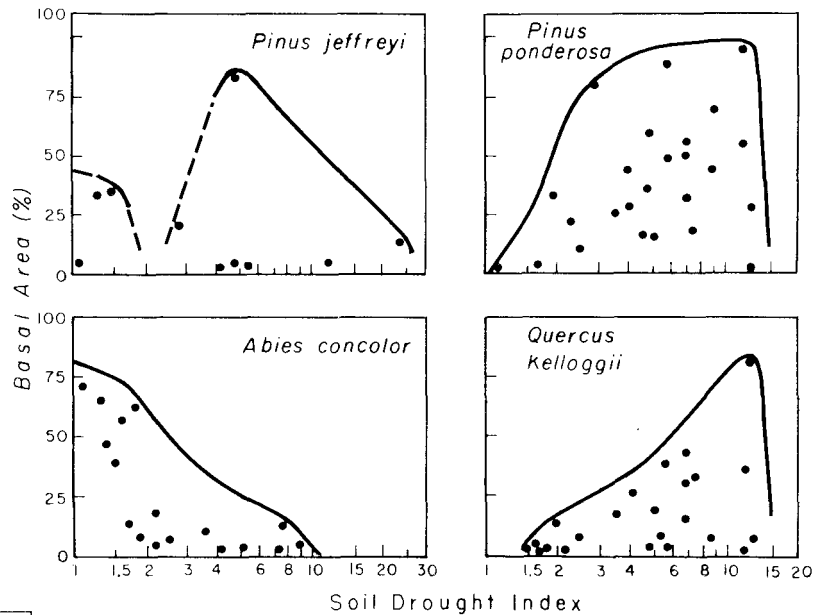


Figure 10.—Relationship of site quality to elevation and SDI gradients. Roman numerals (and A) refer to site quality classes (Dunning 1942) estimated from field observations and S-V Survey data. Numbers refer to plot positions.

Table 6.--Variation in vegetation type, site quality, tree basal area, and Soil Drought Index within the Aiken soil series plots<sup>1</sup>

Plant community type	Site index <sup>2</sup>	Total tree basal area	Soil Drought Index <sup>3</sup>
	----- Square m./ hectare -----		
Foothill woodland: Chaparral phase Plot 2	<sup>4</sup> / 85	14.2	13.3
Mixed conifer forest: Westside pine phase Plot 8	90	28.7	5.8
Plot 13	90	27.3	13.0
Plot 9	95	28.9	12.0
Plot 10	95	66.6	7.0
Plot 7	100	24.9	7.0
Plot 3	100	27.6	7.0
Mixed phase Plot 28	90	39.5	5.9
Plot 5	115+	47.8	5.1
Plot 4	115+	41.5	4.0
Plot 6	130+	34.9	3.6

<sup>1</sup>All plots listed were within areas mapped by Soil-Vegetation Survey as Aiken soil series.

<sup>2</sup>Arvanitis et al. 1964.

<sup>3</sup>Soil Drought Index values for the supplementary plots (3, 4, 7, 13) were estimated from all available soil moisture data.

<sup>4</sup>No pines available for site measurement on the plot--figure was taken from closest available stand 1 km. away.

trees, the site index figures seem to be more sensitive to changes in productivity than the basal area data. A much larger basal area sample would be needed to overcome the effects of past fires and disturbance on basal areas at some plots.

When the plots are aligned along a gradient in site index, only one SDI value (plot 8) is clearly out of line (table 6). This plot had a very dense clay horizon in places, and poor root distribution may have caused less moisture depletion—and thus lower SDI values—than expected in the soil samples.

Site quality estimates for all the plots make an interesting pattern of concentric zones when plotted against elevation and SDI values (fig. 10). The greatest sustained height growth seemed to occur in mesic mixed conifer stands between the 1,000 and 1,500 m. elevation. Early height growth may be more rapid in some lower elevation pine stands, but they do not produce such large trees at maturity. Some fir stands at higher elevations accumulated greater volumes of wood per unit area at maturity than the mixed forests.

#### Brush Characteristics

The lower elevation ends of the transect had the greatest diversity of shrub species (table 7). Plot 2 supported at least 18 shrubby species while plot

34 had 17 species. On the lower fringe of the west-side pine zone some of the chaparral shrubs reached impressive size. Both *Arctostaphylos manzanita* and *A. viscida* approached 9 m. in height in favorable spots. One *A. manzanita* bush on plot 2 was 7.9 m. tall; another on plot 8 had a short trunk 68 cm. in diameter. Although such individual shrubs are massive, repeated disturbance seems necessary to convert the pine and oak communities to "chaparral."

The high-elevation brushfields have the highest density of shrubs. To cross some of these stands you must literally walk on top of the brush. Portions of the rockier and more exposed brushfields are clearly climax in nature. Other parts of these brushfields were mixed conifer or fir forest and have become brushfields through severe burning.

Like the trees, many shrub species tolerate a broad range of moisture conditions. *Amelanchier pallida*, for example (table 7), grows under almost as great a range of conditions as does *Pima jefreyi*. The form of *Amelanchier*, however, changes in the different habitats. In mesic mixed conifer stands (plot 17) grows almost as a small tree while in the juniper woodland (plot 37) it is semi-prostrate. In contrast, *Rubus parviflorus* exhibits a

narrow ecological range (table 7). It grows in canyon bottoms and creek beds as a shrub, but on the plots only very small shrubs appear on the moister spots.

Species like *Prunus subcordata* and *Rhamnus rubra* are widely distributed in the westside forests as large shrubs. On the eastside they often form small, compact, almost spinose shrubs. Some of these eastside forms correspond roughly to formally described taxa, for example *Rhamnus rubra* ssp. *modocensis*. The heavy deer browse pressure

on the eastside plots may contribute to this "east-side growth habit."

Some chaparral species which appear locally in the westside pine stands reappear east of the ridge (Griffin 1966). *Cercocarpus betuloides*, *Ceanothus cuneatus*, and *Rhus trilobata* illustrate this pattern on the plots (table 7). The SDI data suggest that the moisture availability on the two ends of the transect may be similar despite the large difference in total precipitation. Some foothill woodland stands may receive more than three times

Table 7.--Frequency of common shrubs along the Soil Drought Index gradient across the study area, by species

Species	Westside plots <sup>1</sup>																	
	2 13.3	9 12.0	16 7.6	10 7.0	8 5.8	5 5.1	11 4.9	22 4.8	6 3.6	18 2.5	19 2.2	24 2.1	12 1.9	23 1.8	15 1.7	20 1.6	17 1.5	21 1.1
	Frequency percent																	
<i>Ceanothus velutinus</i>	--	--	--	--	--	--	--	39	--	--	--	81	--	--	--	56	--	--
<i>Castanopsis sempervirens</i>	--	--	--	--	--	--	--	90	--	--	4	45	--	(2/)	(3/)	96	6	18
<i>Prunus emarginata</i>	--	--	--	--	--	--	--	7	--	--	--	78	--	--	--	16	--	--
<i>Rubus parviflorus</i>	--	--	--	--	--	--	--	--	(3/)	--	(3/)	--	--	10	(3/)	--	18	--
<i>Paxistima myrsinites</i>	--	--	--	--	--	--	--	--	8	--	--	--	--	--	2	--	8	--
<i>Ribes roezlii</i>	--	--	--	--	--	(3/)	(3/)	--	--	2	2	--	(3/)	4	10	(3/)	6	--
<i>Rosa gymnocarpa</i>	--	--	--	--	--	6	--	--	10	--	(3/)	--	--	10	8	--	12	--
<i>Symphoricarpos acutus</i>	--	--	4	(3/)	--	(3/)	4	6	70	(3/)	--	--	8	14	52	20	30	2
<i>Amelanchier pallida</i>	--	--	--	--	--	--	--	--	(3/)	--	--	--	--	--	6	52	2	10
<i>Arctostaphylos viscida</i>	27	56	2	48	82	2	(3/)	--	--	--	--	--	4	--	--	--	--	--
<i>Arctostaphylos manzanita</i>	33	42	--	20	38	--	6	--	2	--	--	--	6	--	--	--	--	--
<i>Arctostaphylos patois</i>	--	--	44	--	--	--	--	--	--	--	--	100	--	--	--	--	--	--
<i>Purshia tridentate</i>	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
<i>Artemisia tridentate</i>	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
<i>Cercocarpus ledifolius</i>	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
<i>Cercocarpus betuloides</i>	(3/)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
<i>Rhus trilobata</i>	54	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
<i>Ionicera interrupta</i>	3	--	--	(3/)	(3/)	--	--	--	--	--	--	--	--	--	--	--	--	--
<i>Rhus diversiloba</i>	51	30	--	22	8	16	--	--	--	--	--	--	--	--	--	--	--	--
<i>Ceanothus cuneatus</i>	(3/)	4	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	Eastside plot <sup>2</sup>																	
	30 1.3	27 1.4	35 2.8	26 4.1	32 4.9	33 5.5	28 5.9	31 9.0	29 9.0	34 12.0	37 25+							
	Frequency percent																	
<i>Ceanothus velutinus</i>	(3/)	(3/)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
<i>Castanopsis sempervirens</i>	(3/)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
<i>Prunus emarginata</i>	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
<i>Rubus parviflorus</i>	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
<i>Paxistima myrsinites</i>	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
<i>Ribes roezlii</i>	(3/)	(3/)	--	(3/)	--	--	--	--	--	--	--	--	--	--	--	--	--	--
<i>Rosa gymnocarpa</i>	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
<i>Symphoricarpos acutus</i>	--	65	(3/)	--	--	--	--	6	--	--	--	--	--	--	--	--	--	--
<i>Amelanchier pallida</i>	2	50	--	(3/)	--	2	4	--	4	(3/)	(3/)	--	--	--	--	--	--	--
<i>Arctostaphylos viscida</i>	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
<i>Arctostaphylos manzanita</i>	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
<i>Arctostaphylos patula</i>	--	(3/)	20	26	54	2	(3/)	12	12	10	(3/)	--	--	--	--	--	--	--
<i>Purshia tridentate</i>	--	--	50	--	10	10	--	--	50	64	52	--	--	--	--	--	--	--
<i>Aldemisia tridentate</i>	--	--	68	--	2	4	--	--	--	--	36	--	--	--	--	--	--	--
<i>Cercocarpus ledifolius</i>	--	--	(3/)	--	--	28	--	(3/)	--	4	12	--	--	--	--	--	--	--
<i>Cercocarpus betuloides</i>	--	--	--	--	--	4	2	10	4	8	12	--	--	--	--	--	--	--
<i>Rhus trilobata</i>	--	--	--	--	--	2	--	--	8	2	(3/)	--	--	--	--	--	--	--
<i>Ionicera interrupta</i>	--	--	--	--	--	(3/)	--	--	--	2	(3/)	--	--	--	--	--	--	--
<i>Rhus diversiloba</i>	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
<i>Ceanothus cuneatus</i>	--	--	--	--	--	--	--	--	--	(3/)	--	--	--	--	--	--	--	--

<sup>1</sup>Plots ranked along decreasing drought stress up the west slope of the Cascade ridge, SDI listed under each plot number.

<sup>2</sup>Plots ranked along increasing drought stress down the east slope of the Cascade ridge, SDI listed under each plot number.

<sup>3</sup>Species present on plot but not on frequency quadrats.

as much precipitation as the juniper woodland stands, yet these woodland communities are both under comparable drought stress by early summer.

Several forms of *Arctostaphylos* in this region are not satisfactorily treated in the taxonomic literature (Gladish and Mallory 1964; Mallory *et al.*

1965b). A summary of the local manzanita situation in Shasta County in the context of elevation and SDI gradients is given as an example of the usefulness of this index (*fig. 11*).

*Arctostaphylos manzanita* has two forms, a non-glandular, non-sprouting type at lower elevations;

Table 8.--Species used to calculate Vegetation Drought Index (VDI)<sup>1</sup> values for plots representative of three different vegetation types, 1 Shasta County, California, by tentative vegetation drought groups<sup>2</sup>

Tentative vegetation drought groups	Plot		Plot		Plot	
	No. 9 (wests de pine phase)	Total Group values <sup>3</sup>	No. 17 (mixed phase)	Total group value <sup>3</sup>	No. 34 (eastside pine phase)	Total group values <sup>3</sup>
I	--	--	<i>Acer circinatum</i>	--	--	--
	--	--	<i>Rubus parviflorus</i>	--	--	--
II	--	--	<i>Taxus brevifolia</i>	3 X 1 = 3	--	--
	--	--	<i>Castanopsis sempervirens</i>	--	--	--
III	--	--	<i>Smilacina racemosa</i>	2 X 2 = 4	--	--
	--	--	<i>Abies concolor</i>	--	--	--
	--	--	<i>Adenocaulon bicolor</i>	--	--	--
	--	--	<i>Chimaphila menziesii</i>	--	--	--
	--	--	<i>Corallorhiza striata</i>	--	--	--
	--	--	<i>Cornus nuttallii</i>	--	--	--
	--	--	<i>Disporum hookeri</i>	--	--	--
	--	--	<i>Galium triflorum</i>	--	--	--
	--	--	<i>Paxistima myrsinites</i>	--	--	--
	--	--	<i>Pyrola picta</i>	9 X 3 = 27	--	--
IV	<i>Ceanothus integerrimus</i>	--	<i>Berberis piperiana</i>	--	<i>Ceanothus integerrimus</i>	--
	--	--	<i>Campanula prenanthoides</i>	--	--	--
	--	--	<i>Carex rossii</i>	--	--	--
	--	--	<i>Chimaphila umbellata</i>	--	--	--
	--	--	<i>Festuca occidentalis</i>	--	--	--
	--	--	<i>Goodyera oblongifolia</i>	--	--	--
	--	--	<i>Pinus lambertiana</i>	--	--	--
	--	--	<i>Pterospora andromedea</i>	--	--	--
	--	--	<i>Pseudotsuga menziesii</i>	--	--	--
	--	--	<i>Ribes roezlii</i>	--	--	--
	--	--	<i>Rosa gymnocarpa</i>	--	--	--
	--	--	<i>Trientalis latifolia</i>	--	--	--
	--	1 X 4 = 4	<i>Trisetum cernuum</i>	14 X 4 = 56	--	1 X 4 = 4
	--	--	<i>Symphoricarpos acutus</i>	--	--	--
V	<i>Bromus orcuttianus</i>	--	<i>Asarum hartwegii</i>	--	<i>Arctostaphylos patula</i>	--
	<i>Ceanothus prostratus</i>	--	<i>Bromus orcuttianus</i>	--	<i>Festuca idahoensis</i>	--
	<i>Hieracium albiflorum</i>	--	<i>Hieracium albiflorum</i>	--	<i>Haplopappus bloomeri</i>	--
	<i>Horkelia tridentata</i>	--	<i>Iris tenuissima</i>	--	<i>Libocedrus decurrens</i>	--
	<i>Iris tenuissima</i>	--	<i>Libocedrus decurrens</i>	--	<i>Pinus ponderosa</i>	--
	<i>Libocedrus decurrens</i>	--	<i>Melica aristata</i>	--	<i>Sitanion hystrix</i>	--
	<i>Pinus ponderosa</i>	--	<i>Pinus ponderosa</i>	--	--	--
	<i>Polygala cornuta</i>	--	<i>Polygala cornuta</i>	--	--	--
	<i>Sitanion hystrix</i>	--	<i>Pteridium aquilinum</i>	--	--	--
	<i>Viola lobata</i>	--	<i>Pyrola aphylla</i>	--	--	--
	--	10 X 5 = 50	<i>Viola lobata</i>	11 X 5 = 55	--	6 X 5 = 30
VI	<i>Arctostaphylos manzan.</i>	--	<i>Carex multicaulis</i>	--	<i>Castilleja applegatei</i>	--
	<i>Arctostaphylos viscida</i>	--	<i>Galium bolanderi</i>	--	<i>Clarkia rhomboidea</i>	--
	<i>Calochortus tolmiei</i>	--	<i>Quercus kelloggii</i>	--	<i>Collomia grandiflora</i>	--
	<i>Carex multicaulis</i>	--	--	--	<i>Galium bolanderi</i>	--
	<i>Clarkia rhomboidea</i>	--	--	--	<i>Lupinus caudatus</i>	--
	<i>Comandra pallida</i>	--	--	--	<i>Poa sandbergii</i>	--
	<i>Dentaria californica</i>	--	--	--	<i>Prunus subcordata</i>	--
	<i>Galium bolanderi</i>	--	--	--	<i>Quercus garryana</i>	--
	<i>Lathyrus sulphureus</i>	--	--	--	<i>Quercus kelloggii</i>	--
	<i>Lupinus adsurgens</i>	--	--	--	<i>Rhus triloba</i>	--
	<i>Pedicularis densiflora</i>	--	--	--	<i>Senecio aronicoides</i>	--
	<i>Quercus kelloggii</i>	--	--	--	<i>Wyethia mollis</i>	--
	<i>Sanicula bipinnatifida</i>	--	--	--	--	--
	<i>Senecio aronicoides</i>	--	--	--	--	--
	<i>Stipa lemmonii</i>	15 X 6 = 90	--	3 X 6 = 18	--	12 X 6 = 72
VII	<i>Agoseria retrosa</i>	--	--	--	<i>Arabis holboellii</i>	--
	<i>Brodiaea multiflora</i>	--	--	--	<i>Ceanothus cuneatus</i>	--
	<i>Ceanothus cuneatus</i>	--	--	--	<i>Cercis occidentalis</i>	--
	<i>Ceanothus lemmonii</i>	--	--	--	<i>Cercocarpus betuloides</i>	--
	<i>Dodocatheon hendersonii</i>	--	--	--	<i>Cercocarpus ledifolius</i>	--
	<i>Lonicera interrupta</i>	--	--	--	<i>Collinsia parviflora</i>	--
	<i>Ranunculus occidentalis</i>	--	--	--	<i>Eriophyllum lantanum</i>	--
	<i>Rhamnus californica</i>	--	--	--	<i>Juniperus occidentalis</i>	--
	<i>Rhus diversiloba</i>	--	--	--	<i>Leptodactylon pungens</i>	--
	--	--	--	--	<i>Lonicera interrupta</i>	--
	--	--	--	--	<i>Purshia tridentata</i>	--
	--	9 X 7 = 63	--	--	<i>Stipa thurberiana</i>	12 X 7 = 84
VIII	--	--	--	--	<i>Bromus tectorum</i>	--
	--	--	--	--	<i>Penstemon deustus</i>	2 X 8 = 16
Vegetation Drought Index		207/35= 5.9		163/42 = 3.9		206/33 = 6.2

<sup>1</sup>Vegetation Drought Index equals Total group values/Total species.

<sup>2</sup>Less sensitive and rare species were excluded.

<sup>3</sup>Number of species X value assigned to Vegetation Drought Group.

and a glandular, weakly sprouting type at higher elevations. *A. "patula"* has two forms, one a burl forming, sprouting type common on the eastside but only local on the westside. I have called the non-sprouting, non-burl forming type *A. obtusifolia* Piper (Hayes and Garrison 1960). It is called *A. parryana* var. *pinetorum* by the Soil-Vegetation Survey.

The ecological relationships apparent in this sort of graph may help in studying the confusing genetic relationships of these species. Other genera like *Ceanothus* or *Rhamnus* which have many species in the study area would present somewhat similar patterns.

### Herbaceous Flora

Such a large number of herbaceous species occurred on the plots—about 200—that the complete presence and frequency data for them cannot be conveniently listed. Remarks about some herbs are made in the following section on plant indicators, and many herbs are included in the species lists for the representative westside pine, mixed, and eastside pine stands given in *table 8*. More detailed treatment of the herbaceous data, as well as additional notes on trees and shrubs, will be published separately.

## **Plant Indicator Applications**

### **Assigning Vegetation Drought Values**

Using SDI and vegetation dominance data, I assigned as many species as possible to one of eight vegetation drought groups (*fig. 12*). The position of a species' ecological optimum along the SDI gradient helped in this task. It wasn't practical to make the vegetation drought units equal to the SDI units. Also to avoid confusion between the numerical value of the vegetation and soil units, the vegetation drought figures are shown as Roman numerals in this discussion.

For this preliminary effort, the logarithmic SDI scale was divided into five approximately equal units. Three additional units covered species present on the plots but having ecological optimums outside the study area. Thus, group I included the typically riparian species which had a few individuals on the mesic plots. Group II included species which were important in the higher fir forests and brushfields. On the other end of the scale group VIII included xeric species typical of grassy habitats below the study area (*fig. 12*).

When the peak of the frequency curve suggested a clear ecological optimum it was used. For example *Chimaphila metiziesii* corresponds roughly to group III (*fig. 12*). For species with ecological tolerances broad enough to cover several groups, the central value was chosen. If the ecological trend was less clear from the plot data, personal experience and the literature helped to make the decision. No assignments were made for the rare species. Plants like *Fritillaria atropurpurea*, *Lathyrus tracyi*, or *Lotus grandiflorus* might be helpful indicators if more were known about their local ecological behavior.

The widely distributed shrubs like *Amelanchier pallida* and *Rhamnus rubra* could not be used. They might include unrecognizable physiological ecotypes that would each have different indicator values. Some herbs could not be used for the same reason. Thus, *Viola purpurea* should have had three or four physiologically distinct subspecies in different habitats along the transect. Unfortunately, they could be readily distinguished only by the habitats and not by their morphology. The most weedy herbs like *Cryptantha affinis* also were not used.

### Vegetation Drought Index

After assigning drought values to all species with any indicator potential, I calculated a Vegetation Drought Index (VDI) for each plot. Since the logging disturbance on many plots had altered density patterns, I followed Waring's suggestion and did not weight the species data by any density factor. The number and vigor of individual plants influenced the assignment of drought values for each species, but only the presence or absence of a species entered into the calculation of plot VDI. If the species was present, its drought value was added to the plot total.

I tried two methods of calculating the VDI for each locality. First, drought values from the species list for the quadrats were averaged. Then to increase the number of species per sample locality, I used the species list for the entire plot—in effect enlarging the sample size. Both results were similar. Thirteen localities had identical averages by either method. The "plot" average, in which the less common plants had a greater influence, seemed to give a little better ranking than the "quadrat" average. Calculation of VDI for three different plots is illustrated (*table 8*).

One problem anticipated in the use of these methods in the Sierra Nevada vegetation types was

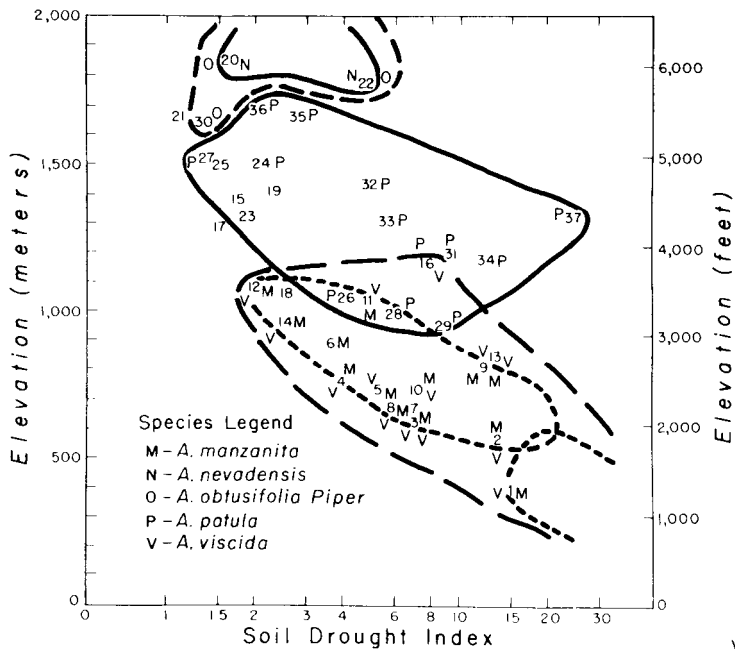


Figure 11.—Distribution of *Arcrostaphylos* species in the study area along elevation and SDI gradients. Numbers indicate plot positions and letters the species present at given plots.

Figure 12.—Examples of how species were assigned to vegetation drought groups prior to the calculation of the Vegetation Drought Index (VDI).

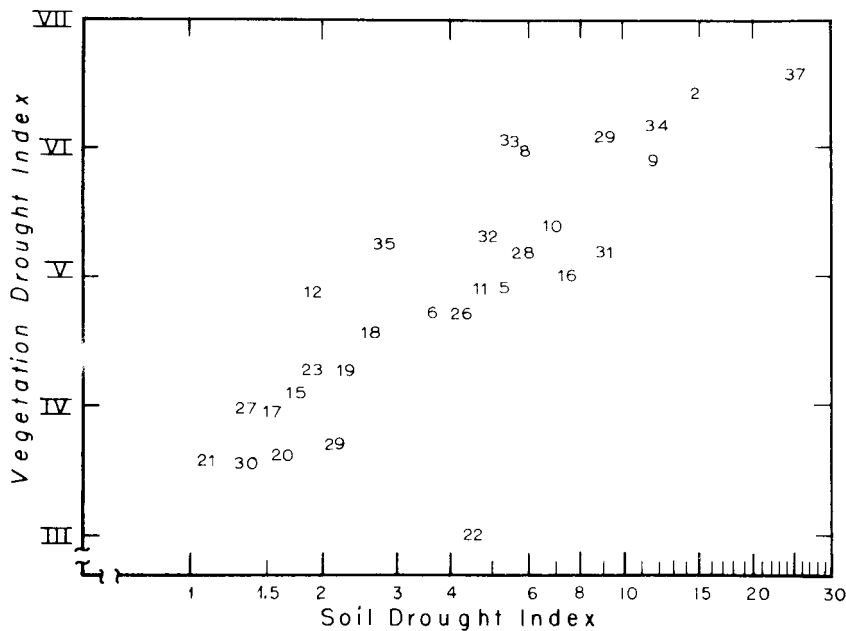
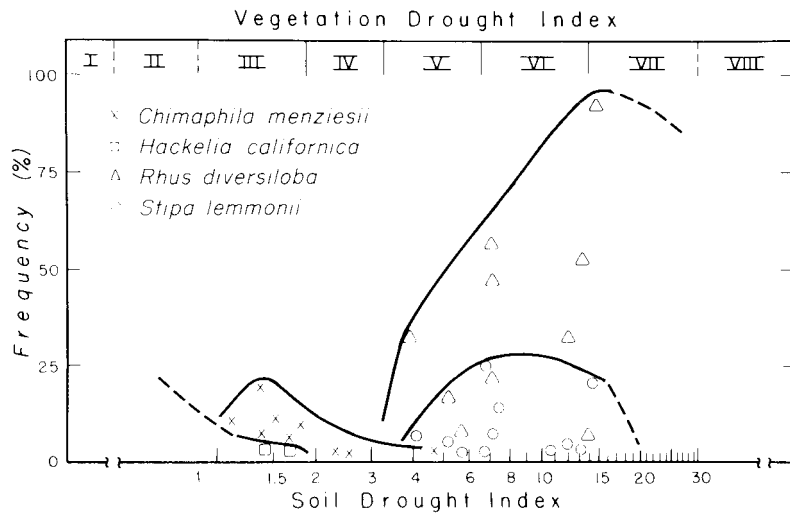


Figure 13.—Relationship between SDI and VDI values. Numbers indicate regular plot positions.



the limited number of species that would be present in some communities. A small number of species is undesirable because of the large influence that any one species can have on the plot average. Rowe (1956) wanted at least 25 indicator species per plot.

This problem did arise, because eight “plots” had less than 25 usable species present. In the “quadrat” lists, nearly half the sample localities had less than 25 species. In higher elevation fir stands this problem would have been acute.

### Comparing Soil and Vegetation Drought Indexes

Plot ranking by the VDI is similar to that given by the SDI (*fig. 13*). Only plot 22 is grossly out of line (*fig. 13*). Its VDI is much lower than would be expected from the soil moisture data. The VDI might be questioned in this case because of the small number of species present—only 17 on the entire plot.

Plot 22 has a very coarse textured profile. Al-

though the soil is droughty in relation to adjacent zonal soils, the cold climate at the higher elevation of this plot may exclude some of the “droughty” plant indicators that appear at lower elevation.

In some cases the VDI appears to be a better estimate of field moisture conditions than SDI. Intuitively, I would rate plot 8 more xeric than plot 10. The SDI does not support this view, but the VDI does. Poor root penetration into the clay samples at plot 8 may have influenced the low SDI values.

On the whole, the SDI seemed to give a satisfactory measure of soil moisture conditions. Weaknesses in the VDI probably contributed more to the scatter of points in *fig. 8* than problems with the SDI. The convenience of the VDI methods, however, justifies more work with this approach. With more refined drought value assignments to the common indicator species, VDI methods might rank pine and mixed conifer plots along moisture gradients far better than any intuitive system.

## Summary and Conclusions

The soil drought index shows promise as a way of describing soil moisture conditions on forest plots. It is not appropriate for surveying amounts of soil water, but is well suited for ranking plots along a gradient of soil moisture availability. For more intensive studies, the slow gravimetric sampling used to follow moisture depletion might be changed to an indirect method. Establishing soil moisture tension curves with the same material that depletion is measured in, however, seems essential. The mechanics of sampling in rocky soil limits the use of this approach, but with adequate sample size, the resulting index does give an ecologically meaningful measure of soil moisture. If this sort of soil moisture stress approach is not adequate, the next step could be to move from the soil into the plants themselves and estimate their internal moisture stress.

The soil moisture results in this study support the conclusions of Fowells and Stark (1965). Soil moisture is not always severely limiting in mixed conifer communities. Except for the surface layer, only in the drier habitats during drier seasons does the average soil moisture tension exceed 15 atmospheres. If competing vegetation were reduced, the lack of soil moisture should not be a problem in establishing reproduction in mixed conifer habi-

tats. In pine communities at lower elevations, however, soil moisture stress may be critical.

This study contributes to the understanding of forest vegetation in eastern Shasta County. It also helps to describe the transition between Sierra Nevada and Cascade vegetation types. Many species not specifically recorded in Shasta County in published floras were collected. Some collections represented minor range extensions.

Ecological connections between the westside and eastside pine communities are revealed in the Burney region. The separation between these types found along the Sierra Nevada may have been altered here by the development of the Pit River Canyon.

The vegetation drought index described in this study is only a preliminary effort. Plant indicators of moisture conditions should be evaluated in the context of nutrient, temperature, and other environmental gradients not yet available.<sup>6</sup>

Results suggest that this index may be of only limited help to a careful observer who is familiar

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<sup>6</sup>Tentative species' drought values are available upon request to the Director, Pacific Southwest Forest and Range Experiment Station, P.O. Box 245, Berkeley, California 94701

with the area in question. His intuitive appraisal of plant indicators may give satisfactory results. But to an observer less experienced with local vegetation, the listing of obvious species and computing a VDI could be useful. The low number of species growing in some communities, particularly at higher elevations, does limit the application of this method. Fortunately, most of the "usable" indi-

cator species can be found in most habitats even after drastic disturbance.

This study also supports previous observations that plant indicator studies must be relatively local. Some species which are associated with mesic habitats in the study area appear to be rather insensitive to moisture conditions 50 km. away in the Klamath Mountains.

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Twenty-nine soil-vegetation plots were studied in a broad transect across the southern Cascade Range. Variations in soil moisture patterns during the growing season and in soil moisture tension values are discussed. Plot soil moisture values for 40- and 80-cm. depths in August and September are integrated into a soil drought index. Vegetation patterns are described in relation to this index. Use of data on species presence for a vegetation drought index is explored.

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