4 Climate

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INTRODUCTION

The climate of southwestern Oregon and northern California is affected by several major influences. Among the most important of these are topography, proximity to the Pacific Ocean, and seasonal variations in upper-level westerly winds. The region is about halfway between the equator and the North Pole, and therefore is alternately under the influence of the active storm track and the subtropical high-pressure system as the seasons change.

Several climate gradients can be found near the region. To the west, the Pacific Ocean moderates the daily and seasonal cycles to a significant degree. To the north, annual precipitation is generally greater, summers are cooler, and the length of the dry season is shorter. To the east, much less precipitation falls, the temperature varies more from summer to winter, and winters are considerably cooler. To the south, annual precipitation is also lower, the dry season is considerably longer, and temperatures in both winter and summer are higher. In general terms, the region has a modified Mediterranean climate.

However, conditions at a particular place may vary widely from the general climate of the region. The climate in the immediate vicinity of a seedling, the "microclimate," is influenced to some extent by the presence of the seedling itself and of nearby organisms, by local physical conditions, and by the larger-scale processes at work within the region and beyond it. All these influences, large and small, operate simultaneously. The climate of an area is, therefore, the result of processes operating over a broad continuum of spatial scales, ranging from the dimensions of the seedling to those of the planet. In this manner, the environment of a growing plant is intimately linked to the rest of the world.

Climate and weather affect seedlings in a number of ways, most directly by providing the moisture and radiation a plant needs to grow. Many physical and biochemical processes at work in and around the plant are sensitive to temperature. Weather is also a source of stress to the plant, subjecting it to excessive or deficient levels of heat, moisture, wind, radiation, or humidity. These elements affect the plant's growth rate, and extreme levels of any of them can lead to mortality. Several indirect influences also exist; a stressed plant is more susceptible to insect attack and disease. Climatic factors can affect the health of disease-producing organisms or their hosts. The growth and life cycles of insect pests, for example, are greatly affected by temperature.

To illustrate the variety of ways in which atmospheric conditions interact with a biological community, consider a fire. Let us say that favorable weather conditions in previous years promoted an insect outbreak that killed a large number of trees. Now a warm and rainless summer dries out the standing dead timber. Another weather event, a lightning storm, ignites the dry wood. Weather conditions influence the firefighting effort, perhaps by trapping smoke and limiting visibility for ground-based operations (or by allowing smoke to rise and affect airborne operations), or by blowing embers over fire lines. The vegetative ground cover is burned, and the local microclimate is changed. The next generation of trees will have to become established on an exposed hillside that may favor a competitor species. Heavy rains now run off more quickly than before, carrying valuable topsoil. After a number of years, the area returns to its former state and the cycle begins anew. We can see in this example that climate and weather events on several spatial and temporal scales are interwoven into the natural history of the area.

The climatic elements most important to reforestation are temperature, moisture, and radiation. Fortunately, precipitation and temperature are relatively easy to measure, and many years of data have accumulated at a number of sites in the region. Long-term averages of these and other quantities are commonly believed to constitute "the climate." This is not a sufficient description, however. Seedlings respond both to mean conditions and to the inevitable departures from mean conditions, and they must be able to survive such departures. For this reason, a more complete description of climate should include the expected degree of variation around average conditions and the frequency and character of rare events that can have disastrous consequences for reforestation.

Climate involves balances in flows of energy and mass. As such, climate should not be thought of as static, but rather as a complex and dynamic interaction among a number of interrelated processes. Because climate is always subject to fluctuations, some aspect of it will nearly always appear to be changing. The data from the period for which we have measurements should be regarded as a statistical sample of the unknown "true" climate.

This chapter discusses the major climatic elements of precipitation and temperature, other climate elements that affect reforestation success, and the significance of microclimate. The chapter closes with a discussion of the potential for future changes in climate.

PRECIPITATION

Seasonality

Winters in southwestern Oregon and northern California are very wet and summers are very dry. The wettest month is typically either December or January; January tends to be the slightly wetter month in northern California (see NOAA 1982a). The wettest month brings 16-22 percent of the average annual precipitation (Table 4-1). Over most of the region, about 35-45 percent f the average annual precipitation falls during he period comprising December through January. November (in Oregon) and February (in California) are the next wettest months, each accounting for 12-16 percent of the annual total. Thus, about 45-55 percent of the yearly total occurs during the 3 wettest months, and 65-75 percent occurs from November through February.

The driest month is July, which brings 0-2 percent of the annual total throughout the region. Most stations receive less than 5 percent of their annual precipitation during the summer months from June through August. Despite abundant ocean water nearby, atmospheric water content is not high and no mechanism is available to remove the water from the air. About 4 years in 10, Medford experiences either a rainless July or a rainless August; it is not uncommon for a location to go 4-6 weeks without any precipitation. The area's dry summers contribute greatly to the difficulty a seedling faces in becoming established.

More detailed climate information is readily available for Oregon than for northern California. One site with a good data record is on the summit of Sexton Mountain (elevation 3,800 ft), 10 miles north of Grants Pass, where a first-order weather observatory has operated for several decades. Many features of the climate of this site are representative of middle-elevation locations where reforestation operations frequently occur. As an example, data from Sexton Summit have been used to calculate the probability that various levels of precipitation would be exceeded in a 15-day period as a function of the day of the year (Figure 4-1). Conversely, they have also been used to estimate the probability of measurable precipitation during a range of durations from 1 to 15 days. By approximately mid-November at Sexton Summit, the probability of measurable precipitation on any given day has reached a plateau for the winter. From this point until mid-March, there is about a 55-percent chance of measurable precipitation on any given day.

Table 4-1. Percent of annual precipitation by month at selected sites and mean annual total in inches. Data from 1951-1980. From NOAA (1982a) and data archives of Oregon Office of the State Climatologist.

Site	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Annual*
Oregon													
Ashland	15	9	10	7	7	5	2	3	4	9	13	16	18.90
Brookings	17	13	12	7	5	2	1	2	3	8	15	16	76.22
Buncom 2 SE	17	11	10	6	6	4	1	3	4	8	13	18	23.10
Cape Blanco	18	13	12	7	4	2	1	2	3	7	15	17	76.70
Crater Lake Nat'l Park	17	12	12	7	4	3	1	2	3	8	14	17	66.87
Gold Beach	18	13	13	7	5	2	0	1	3	7	14	17	82.67
Grants Pass	20	13	11	5	4	2	1	1	3	8	14	18	32.31
Klamath Falls	16	9	9	5	7	6	1	4	4	9	13	17	13.65
Medford Nat'l Weather Serv.	17	11	9	5	6	3	1	2	4	8	15	18	19.84
Powers	19	13	13	7	5	2	0	1	2	7	14	18	61.95
Prospect 2 SW	17	11	11	6	5	3	1	2	3	9	15	17	41.80
Riddle	19	11	11	6	4	2	1	2	3	8	15	19	31.61
Roseburg	18	12	11	6	5	3	1	2	3	8	15	18	33.35
Sexton Summit	18	11	11	6	5	3	1	2	3	8	16	17	38.14
California													
Big Bar Rngr. Stn.	21	15	11	5	3	1	0	1	2	6	14	19	38.96
Callahan	18	13	9	6	4	4	2	2	3	7	14	19	21.64
Crescent City	18	13	13	7	5	2	0	1	3	8	15	16	67.15
Fort Jones Rngr. Stn.	21	12	9	5	3	3	2	2	3	6	13	20	22.48
Gasquet Rngr. Stn.	19	13	13	7	4	1	0	1	2	7	15	18	94.22
Greenview	22	14	8	5	3	3	1	1	2	6	14	20	21.85
Happy Camp Rngr. Stn.	22	14	12	5	3	1	0	1	2	7	14	20	55.67
Harrison Gulch	21	16	11	7	3	2	0	1	2	6	13	18	36.34
Hilts	20	12	10	4	4	3	1	2	3	7	14	19	22.48
Klamath	18	13	13	7	4	1	0	1	3	7	15	17	81.37
Mt Shasta Nat'l Weather Serv.	19	15	11	7	4	2	1	1	2	5	14	16	37.05
Orleans	20	14	12	6	3	1	0	1	2	7	15	19	53.84
Redding Fire Stn.	21	15	12	7	3	2	0	1	3	5	14	17	40.95
Shasta Dam	21	16	12	7	3	2	0	1	2	5	14	17	61.92
Weaverville Rngr. Stn.	21	14	11	6	3	2	0	1	2	6	14	19	39.19
Yreka	19	11	9	5	4	4	2	3	3	7	12	20	19.20

Spatial Variations

Precipitation patterns are greatly affected by topography. Therefore, it is not surprising that annual precipitation varies considerably throughout the region, by a factor of nearly 5 at established climate stations and approximately 10 when remote sites are included. A map of annual precipitation in the five southwesternmost counties of Oregon was prepared by Froehlich et al. (1982) after a careful analysis of available data. No such detailed map is available for northern California. McNabb et al. (1982) have also produced a dry-season precipitation map for southwestern Oregon for May through September, the period when most seedling stem growth occurs.

Over the nearby ocean waters, annual precipitation is estimated to be near 30 inches (Elliott and Reed 1973, Reed and Elliott 1973). As moisture-laden air ascends over the coastal mountains, it

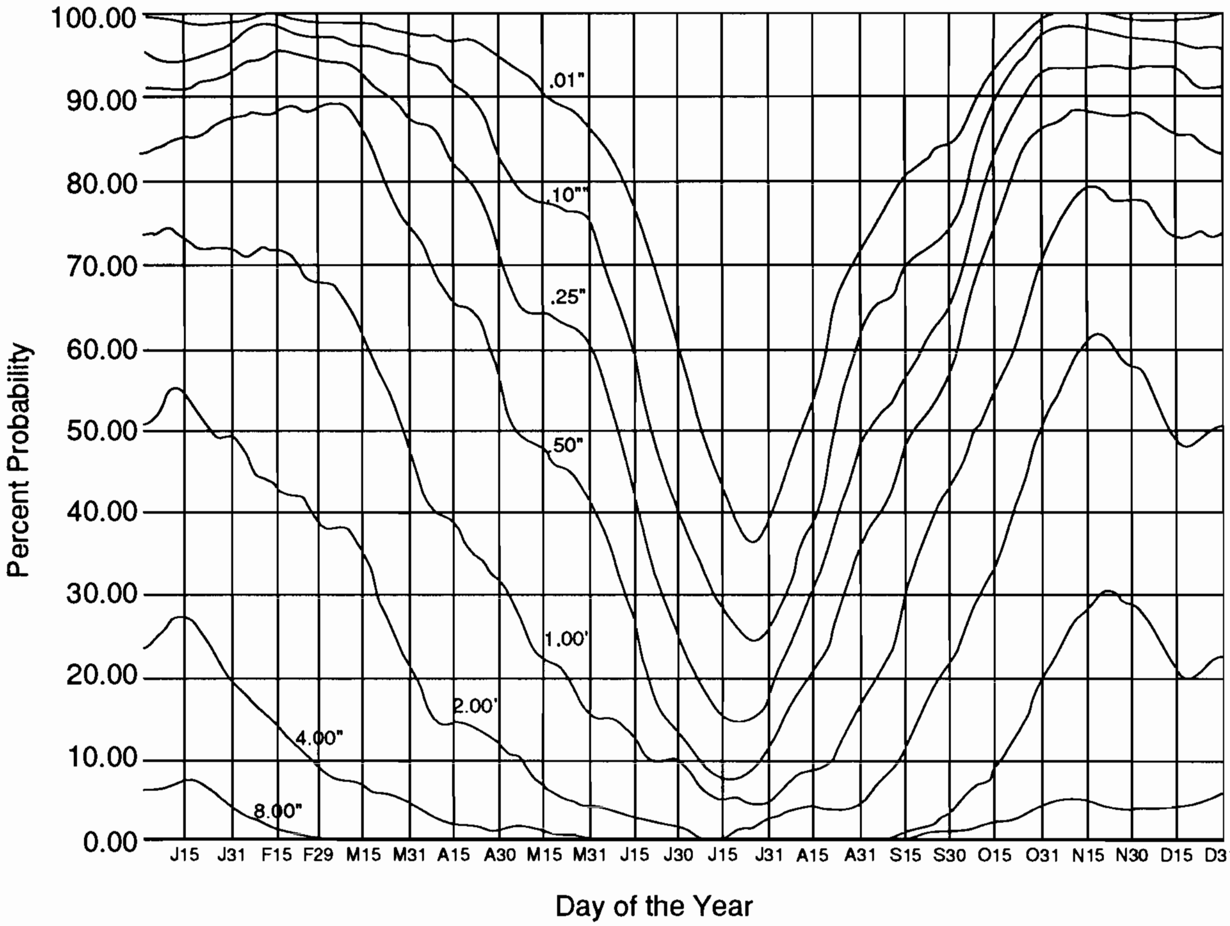

Figure 4-1. Probability of indicated amount of precipitation at Sexton Summit in a 15-day period, starting on the plotted date, for various threshold amounts. Data from 1948-1988; smoothed with a 30-day filter. Example: for the 15-day period starting on May 15, there is a 90-percent probability of measurable precipitation and a 22-percent probability of at least 1 inch.

drops most of its moisture on the way; the stretch of coast from Cape Blanco southward receives approximately 80 inches of precipitation in a year, whereas much of the area immediately inland receives over 100 inches. Average annual precipitation reaches 130 inches northwest of Agness and over 160 inches on the ridgetops northeast of Brookings.

A second area of high precipitation is found along the rounded crest of the Cascades. From Crater Lake southward, the highest totals are just above 70 inches per year at the most elevated sites. To the south, as the Cascades diminish in height to the uplands of the Dead Indian Plateau, maximum mean annual precipitation decreases to about 35 inches. Along the crest of the Siskiyou Mountains near the state border, amounts range from 50-70 inches.

In western Oregon and northern California, an east-west minimum of annual mean precipitation coincides closely with the route of Interstate Highway 5. The lowest values in western Oregon are found near Medford, which receives about 20 inches of precipitation annually.

In northern California, the Smith River drainage is very wet, with mean annual values reaching as high as 160 inches (Winston and Goodridge 1980). Camp Six, at a 3,700-ft elevation 6 miles east of Gasquet, received 257.9 inches of precipitation from September 1982 through

October 1983. East of this area, amounts decline to as low as 10 inches about 20 miles south of the state border along Interstate 5.

Mean annual precipitation is closely related to elevation. Higher-elevation sites receive more precipitation than nearby valley locations. Isolated peaks receive more than adjacent valleys but not as much as broadly elevated uplands, because air can bypass the peaks but not the plateaus.

The frequency of precipitation does not vary spatially as greatly as does the amount. Elevated areas tend to experience more days with measurable precipitation. However, the increased number of wet days cannot alone account for the large differences in mean annual precipitation. Rather, at wetter sites, more rain falls on rainy days.

Precipitation Rates

As winter approaches, the probability of heavy rains capable of causing road damage, erosion, landslides, and other disruptive effects begins to increase, reaching a maximum by early to mid-November. The probability of heavy precipitation episodes begins to decrease during the second half of January (Figure 4-1), although the probability of lighter amounts remains high until past the end of February.

Maps have been prepared (NOAA 1973) showing 24-hour precipitation values that can be expected once in 2 years, or said differently, those amounts that can be expected approximately 50 times in 100 years. In general, about once every other year locations in this region can expect to receive in 24 hours an amount between 5 and 10 percent of the mean annual precipitation. The upper end of that range applies to drier places, such as the Medford-Ashland area, and the lower end to the wetter places in the Cascades and Coast Range. Precipitation totals of approximately twice these percentages can be expected about once in 100 years. However, more recent information (for example, the data used by Froehlich et al. 1982), reveals that NOAA maps may underestimate intensity-duration values, in some of the remote, wetter regions (for example, east of Brookings) by as much as 25 percent.

The large annual precipitation amounts are mostly the result of persistent, moderate rains. It is unusual to see rains heavy enough to amount to even 1 inch in an hour. The rare higher hourly amounts tend to come in the warmer months, when deep convective clouds, including thundershowers, can form more easily.

TEMPERATURE

Diurnal and Annual Cycles

The Pacific Ocean, with its slow warming and cooling, acts as a giant reservoir of thermal energy. Consequently, the ocean greatly modifies the temperature regime along the immediate coastline. The ocean warms slowly through late August, and the warmest month at coastal locations—either August or September—is only about 9-12°F warmer than January, the coolest month.

By contrast, July is the warmest month at inland locations, although in many places August is only slightly cooler. The more rapid thermal response over land results in an annual temperature cycle that more closely follows the cycle of solar radiation received. The result is a modified continental climate that begins just a few miles inland. Both the daily range and the annual range of temperature are greater than at the coast, and, especially in summer, locations less than 10 miles inland can warm an additional 10-20 degrees or more before the arrival of the afternoon sea breeze. In July, for example, the average daily temperature range at Brookings is 16°F, compared with 23°F at Coquille (10 miles from the coast), 37°F at Illahe (17 miles), and 39°F at Cave Junction (28 miles). Minimum temperatures during July are similar at all these locations. Maximum temperatures on mid-summer days can differ by 40-50 degrees between coast and interior. Frequently the coolest summer days along the coast are the hottest at interior locations.

Diurnal and Spatial Influences on Temperature

When the moisture content of the air is low, as it is in this region during the summer, the surface warms rapidly during the day and cools rapidly at night, leading to a large difference between morning and afternoon temperatures. However, because clouds absorb infrared radiation very effectively, and because they emit more of it back to the

Table 4-2. Extreme temperatures at Sexton Summit (a mountaintop at elevation 3,840 ft), Howard Prairie Dam (a plateau at elevation 4,760 ft), and Prospect (a valley bottom at elevation 2,480 ft). Data from 1961-1986. From Oregon Office of the State Climatologist.

	Sexton Summit	*Howard Prairie Dam*	*Prospect*
Maximum temperatures (°F).			
Average annual maximum	56°F	56°F	65°F
Average July maximum	75	79	87
Average January maximum	42	38	47
Average annual extreme maximum	91	93	101
Highest maximum	97	100	110
Days with maximum of:			
80°F or higher	31.9 days	48.8 days	95 days
85°F or higher	12.0	22.0	66
90°F or higher	2.7	5.2	38
95°F or higher	0.4	0.7	16
100°F or higher	0.0	0.7	3
Days with maximum of:			
32°F or lower	20.2 days	20.0 days	1.2 days
28°F or lower	4.3	7.0	0.3
24°F or lower	1.0	1.8	0.1
20°F or lower	0.4	0.7	0.0
16°F or lower	0.1	0.2	0.0

	Sexton Summit	*Howard Prairie Dam*	*Prospect*
Minimum temperatures (°F).			
Average annual minimum	40°F	31°F	36°F
Average July minimum	51	43	47
Average January minimum	31	19	28
Average annual extreme minimum	15	-2	8
Highest minimum	75	59	66
Lowest minimum	-2	-20	-8
Days with minimum of:			
45°F or higher	116 days	36 days	76 days
50°F or higher	71	8	31
55°F or higher	38	1	8
60°F or higher	17	0	1
Days with minimum of:			
32°F or lower	108.0 days	209.0 days	137.0 days
25°F or lower	28.2	104.6	38.7
20°F or lower	5.8	58.0	12.6
15°F or lower	1.5	29.3	5.3
10°F or lower	0.3	14.5	2.1
5°F or lower	0.2	7.4	0.8
0°F or lower	0.0	3.0	0.3

surface than clear skies, the surface does not cool nearly as quickly on cloudy nights as on clear nights.

The column of air above broadly elevated regions generally contains less water vapor, and thus usually cools more efficiently, than air over low-elevation sites. Moreover, extended surfaces such as plateaus heat and cool more readily than do isolated mountaintops at the same elevation. A comparison between the summit of Sexton Mountain (3,840 ft) and Howard Prairie Dam at an essentially similar elevation (4,760 ft) on the Dead Indian Plateau shows this difference (Table 4-2). These two sites have the same annual mean maximum temperature (56°F). However, the plateau site is warmer in July and cooler in January and records more extreme temperatures in both months.

Temperature Distributions and Extremes

In order to appreciate the day-to-day variability of weather, it is instructive to think of its ele-

Table 4-3. Average annual number of days with temperature above selected thresholds, and average annual extreme maximum temperature. From NOAA (1982b) and Oregon Office of the State Climatologist.

Site	Years	Temperature threshold (°F) 70	75	80	85	90	95	100	105	Average annual extreme maximum temperature
Oregon										
Medford	51-80	-	-	107 days	80 days	53 days	27 days	9 days	1 day	104°F
Ashland	51-80	-	-	87	59	31	11	2	0	100
Lost Cr Dam	70-86	-	-	103	79	52	27	10	2	105
Prospect	51-80	-	-	96	68	39	16	3	0	101
Grants Pass	51-80	-	-	114	84	52	24	7	1	103
Cave Junction	62-86	153	128	101	72	44	19	5	1	102
Ruch	63-86	-	-	108	80	50	23	6	1	103
Illahe	51-80	153	125	85	61	36	17	6	1	104
Powers	51-80	126	81	40	14	4	1	0	0	97
Brookings	51-80	-	-	9	4	2	1	0	0	94
Howard Pr Dam	61-86	-	-	49	22	5	1	0	0	93
Sexton Summit	51-80	89	60	33	12	3	0	0	0	91
Crater Lake	51-80	48	23	6	1	0	0	0	0	83
California										
Redding	51-80	214	187	158	131	103	74	40	14	111
Yreka	51-80	157	132	107	79	52	24	6	0	102
Eureka	51-80	6	2	0	0	0	0	0	0	77
Mount Shasta	52-80	137	109	80	50	22	5	0	0	97
Red Bluff	51-80	210	182	154	127	99	68	36	13	111
Big Bar Ranger Station	52-80	183	161	138	115	87	62	32	12	111
Happy Camp	51-80	175	153	129	106	80	52	26	7	107

ments in terms of their probability distributions, rather than merely their mean values, and of the spatial variability in these distributions. For example, the median daily minimum atop Sexton Summit at the end of July is about 52°F, but half the minimums are either below 48°F or above 58°F. In contrast, the median minimum on the same day in the bottom of a narrow valley near Prospect, 1,400 ft lower, is 47°F, with half the minimums either below 43°F or above 51°F. The warmest minimums annually experienced in this valley (near 60°F) are seen on approximately 20 percent of the days atop Sexton Summit. Available records also show that frost has not been observed at Sexton Summit from early June until late September, whereas temperatures have reached close to freezing in one year or another on most days at Prospect, even in mid-summer.

With abundant sunshine and few clouds in the summer, spells of hot or very warm weather frequently occur in the area. There is significant variation from site to site in the average number of days that temperatures exceed specified thresholds (Table 4-3). Flint and Childs (1983), Childs and Flint (1987), and Helgerson (1990) have pointed out the effects of high temperatures on seedlings (see Chapters 6, 8, and 16). During a heat wave in August 1981, soil temperatures an inch below the surface reached over 130°F on a south-facing slope near 4,000 ft in elevation (Childs and Flint 1987). By contrast, the air temperature at Medford reached "merely" 114°F during this episode.

At Prospect, near the end of July, the average maximum is about 89°F, with a 20-percent probability that the temperature on any given day may reach 95°F or higher. With clear skies and a south

Table 4-4. Probabilites of temperature thresholds. (Continued on next page)

	Years	Percent probability				
		10	30	50	70	90
Part a. Probability that latest instance of indicated temperature threshold will have occurred by date given. Mid-summer is July 1. *Does not occur frequently enough to calculate probability.						
32°F						
Ashland	51-80	Apr 22	May 4	May 13	May 21	Jun 2
Grants Pass	51-80	Apr 15	Apr 24	Apr 30	May 6	May 14
Roseburg	51-80	Mar 26	Apr 11	Apr 22	May 3	May 19
Howard Prairie Dam	61-86	Jun 3	Jun 11	Jun 16	Jun 25	Jun 29
Sexton Summit	48-86	May 12	May 21	May 25	May 31	Jun 7
Prospect	31-86	May 16	May 27	Jun 7	Jun 13	Jun 24
Crater Lake	31-86	Jun 19	Jun 25	Jun 28	Jun 30	Jun 30
Redding	51-80	Jan 15	Feb 8	Feb 24	Mar 12	Apr 5
Yreka	51-80	Apr 29	May 9	May 15	May 21	May 31
28°F						
Ashland	51-80	Mar 22	Apr 5	Apr 15	Apr 24	May 8
Grants Pass	51-80	Mar 6	Mar 22	Apr 1	Apr 12	Apr 27
Roseburg	51-80	Feb 3	Feb 24	Mar 10	Mar 24	Apr 14
Howard Prairie Dam	61-86	May 4	May 12	May 22	May 30	Jun 5
Sexton Summit	48-86	Apr 11	Apr 29	May 4	May 10	May 18
Prospect	31-86	Apr 25	Apr 30	May 10	May 18	May 29
Crater Lake	31-86	Jun 4	Jun 17	Jun 22	Jun 27	Jun 29
Redding	51-80	*	*	Jan 16	Feb 3	Feb 27
Yreka	51-80	Apr 6	Apr 18	Apr 26	May 4	May 15
24°F						
Ashland	51-80	Feb 9	Mar 1	Mar 14	Mar 27	Apr 16
Grants Pass	51-80	Jan 7	Jan 29	Feb 12	Feb 27	Mar 20
Roseburg	51-80	*	*	Jan 18	Feb 6	Mar 4
Howard Prairie Dam	61-86	Apr 15	Apr 20	Apr 26	May 1	May 12
Sexton Summit	48-86	Feb 4	Mar 17	Mar 30	Apr 20	Apr 29
Prospect	31-86	Mar 3	Apr 1	Apr 10	Apr 21	May 6
Crater Lake	31-86	May 17	May 28	Jun 4	Jun 10	Jun 27
Redding	51-80	*	*	*	*	Jan 15
Yreka	51-80	Mar 1	Mar 17	Mar 28	Apr 8	Apr 24

slope, many seedlings may experience dangerously high temperatures at the soil surface and just below it.

Seedlings must be adapted to withstand both isolated extremes and periods where thresholds are exceeded for many consecutive days. The cumulative stress of the latter can be especially taxing. At Medford, air temperatures will reach 90°F on an average of 10 consecutive days per year, and 100°F on 3 consecutive days. About once in 10 years, the corresponding figures are 25 and 7 consecutive days. The longest such strings between 1928 and 1986 were 34 and 10 consecutive days, respectively. For such a warm climate, these spells are actually rather short. One interesting facet of the climate of this region is that the proximity of the ocean prevents really prolonged hot spells. After several days of hot

Table 4-4, continued. Probabilites of temperature thresholds.

	Years	Percent probability				
		10	30	50	70	90
Part b. Probability that earliest instance of indicated temperature threshold will have occurred by date given. Mid-summer is July 1. *Does not occur frequently enough to calculate probability.						
32°F						
Ashland	51-80	Sep 26	Oct 6	Oct 12	Oct 19	Oct 29
Grants Pass	51-80	Sep 26	Oct 11	Oct 20	Oct 30	Nov 13
Roseburg	51-80	Oct 11	Oct 24	Nov 2	Nov 11	Nov 25
Howard Prairie Dam	61-86	Jul 3	Aug 31	Sep 10	Sep 12	Sep 22
Sexton Summit	48-86	Sep 28	Oct 7	Oct 22	Nov 9	Nov 15
Prospect	31-86	Aug 24	Sep 8	Sep 17	Sep 25	Oct 9
Crater Lake	31-86	Jul 1	Jul 2	Jul 5	Jul 12	Aug 8
Redding	51-80	Nov 6	Nov 18	Nov 27	Dec 5	Dec 17
Yreka	51-80	Sep 25	Oct 3	Oct 10	Oct 16	Oct 24
28°F						
Ashland	51-80	Oct 15	Oct 26	Nov 2	Nov 9	Nov 19
Grants Pass	51-80	Oct 24	Nov 9	Nov 20	Dec 2	Dec 18
Roseburg	51-80	Oct 29	Nov 15	Nov 27	Dec 8	Dec 26
Howard Prairie Dam	61-86	Sep 13	Sep 24	Oct 13	Oct 17	Oct 27
Sexton Summit	48-86	Oct 22	Nov 8	Nov 14	Nov 25	Dec 12
Prospect	31-86	Sep 17	Sep 28	Oct 7	Oct 19	Oct 31
Crater Lake	31-86	Jul 3	Aug 2	Sep 5	Sep 15	Oct 1
Redding	51-80	Nov 21	Dec 10	Dec 25	*	*
Yreka	51-80	Oct 14	Oct 23	Oct 29	Nov 4	Nov 13
24°F						
Ashland	51-80	Oct 29	Nov 13	Nov 23	Dec 3	Dec 17
Grants Pass	51-80	Oct 28	Nov 22	Dec 9	Dec 26	*
Roseburg	51-80	Nov 9	Dec 2	Dec 18	*	*
Howard Prairie Dam	61-86	Oct 8	Oct 18	Oct 31	Nov 9	Nov 21
Sexton Summit	48-86	Nov 11	Nov 20	Dec 4	Dec 24	*
Prospect	31-86	Oct 8	Oct 28	Nov 12	Nov 24	Dec 14
Crater Lake	31-86	Sep 11	Sep 20	Sep 29	Oct 2	Oct 16
Redding	51-80	Dec 18	*	*	*	*
Yreka	51-80	Oct 30	Nov 9	Nov 16	Nov 23	Dec 3

weather, a pressure difference will usually develop between the land and ocean and the cool maritime air will spread inland. The hot weather thus sets into motion events that will later cause the region to cool.

The length of the growing season generally decreases with decreasing annual mean temperatures. Local factors at a particular site may lengthen or shorten the growing season from the areal average for that elevation. Data on freezes and freeze-free periods at selected sites in the region have been tabulated by the National Climatic Data Center and state climate offices (Table 4-4). At higher elevations, frost is possible almost any day of the year, especially if the topography features expanses of level ground or shallow basins that keep cold air from draining away. Further details are presented below in the section on microclimate.

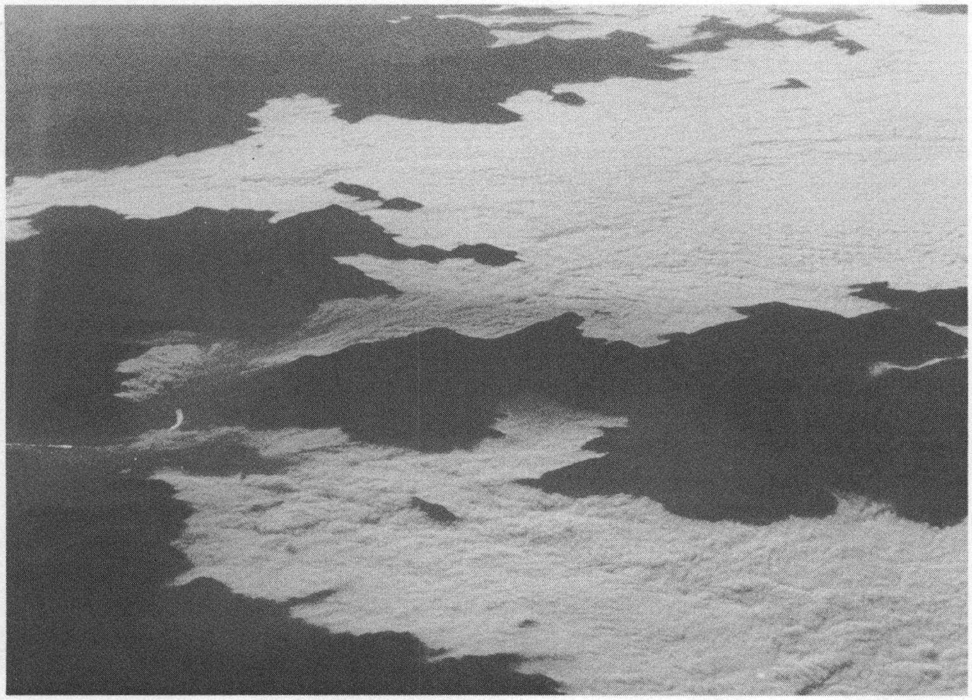

Figure 4-2. Fog trapped below an inversion in the Medford area on a winter day, as seen from a commercial airliner.

Vertical Variations

Averaged over long periods, temperature decreases with elevation. On many occasions, however, an inversion—a layer of warm air atop a layer of cold air—will be found. This situation occurs for two principal reasons: (1) air has been heated or cooled in place at different rates in the two layers, or (2) air with different temperatures has moved in horizontally at different rates.

Since surfaces radiate more effectively than the atmosphere, air near the surface often cools more overnight than the air above does. The resulting "nocturnal inversion" is a common occurrence on clear summer nights. Frequently the surface layer cools sufficiently for the water vapor in it to condense as fog droplets. This morning fog reflects the sun's energy away. On short winter days, the feeble sunlight is often not able to burn off these fog layers during the few daylight hours, and they may persist for extended periods. On these days mountain slopes and tops above a certain elevation will be basking in warm sunlight, while adjacent valley bottoms remain cool under a featureless, low, gray overcast (Figure 4-2).

OTHER CLIMATE ELEMENTS

Thunderstorms

Thunderstorms and their associated hazards are infrequent in this region; however, remote, mountainous areas may be underrepresented by these airport statistics. Along the coastline, most thunderstorms are associated with and often embedded in large-scale cyclonic storms moving onshore in winter. Over the Cascades, most thunderstorms occur in the summer months, generally in relatively unusual situations where tropical air is brought north by southerly winds which may have a component from the east. The annual number of thunderstorms generally increases away from the coast. A network of lightning detectors has recently been deployed throughout much of the West, capable of accurately pinpointing the times and positions of individual lightning strikes. Future decades will doubtless bring more accurate lightning climatologies.

Snow

Snowfall is infrequent near sea level, but its occurrence increases greatly with elevation. Monthly snowfall in the winter is rather modest, even at 3,800-ft Sexton Summit. However, the snowfall frequency distribution is highly skewed, and very large amounts have occurred. The Snow Survey, a branch of the USDA Soil Conservation Service, has for many years maintained a network of stations where snow depth and snow water content are measured regularly. Locations with measurements at a range of elevations, such as King Mountain and Red Butte, show a clear progression in average snow water content from lower to higher elevations. The averages for lower elevations are likely to include a number of years with no snow on the ground.

Seedlings at higher elevations spend a larger portion of the year in and under the snow. Snow is an excellent insulator, preventing the flux of heat from the relatively warm soil below. The soil under a foot of snow can remain unfrozen even when air temperatures plunge below 0°F for 2-3 weeks. If the snow is deep enough to cover the seedling entirely, weather variations above the snowpack may be of little consequence. The same weather variations, by contrast, may have dire consequences if the plant is partially or wholly exposed.

Severe cold spells when the ground is bare can damage not only plants but also structures such as pipes, culverts, and roads. Seedlings may be harmed by either direct frost damage to unhardened new growth or the mechanical effects of frost heaving. Seedlings in cold or frozen soil can also be subjected to high moisture stress from winter desiccation if they are exposed to warm, dry winds (Chapter 6).

Wind

In summer, a semi-permanent, subtropical high-pressure system exists over the eastern Pacific Ocean. Clockwise circulation around this system leads to persistent north winds at the surface along the coast and in the lower atmosphere at inland sites. These north winds seldom exceed moderate speeds but blow rather steadily.

In winter, this high-pressure cell is no longer present, and winds from the south and west are more frequent. The strongest winds are usually from the southwestern quadrant, typically ahead of an approaching frontal system. Monthly average wind speeds and "fastest miles" (the average speed during the shortest time interval on record when 1 mile of wind passed by the anemometer) have been determined for several airports in the region (Wantz and Sinclair 1981). Peak gusts are typically 30-50 percent higher than the fastest mile. Along the coast, Cape Blanco averages about 250 hours per year with average hourly speeds of 50 mph or more (Wade and Wittrup 1987), and winds exceed 100 mph almost every year. Wind speeds on exposed ridges in southwestern Oregon and northern California probably reach 90-100 mph at least once in most winters. In the free air over Medford (free air is air not in close proximity with the surface), average monthly wind speeds are weaker in summer than in winter.

Topography affects wind speed, as revealed by comparison of the speed distributions between the exposed mountaintop of Sexton Summit and the relatively sheltered valley bottom where the Medford airport is located. In winter, Medford frequently records near-calm conditions, when upper winds are unable to scour out the cold air trapped in the closed Rogue River basin. In summer, moderate surface winds are more common, but winds higher than about 25 mph are quite uncommon. Sexton Summit is windier in both seasons than Medford, and wind speeds of 15 to 25 mph are considerably more frequent, but summer winds there, as at Medford, seldom exceed 25 mph.

Consistent, high-quality wind data are difficult to find away from airports. The recent deployment of Remote Automated Weather Stations (RAWS) by the Forest Service and the Bureau of Land Management will improve our future knowledge of wind statistics in forested regions, but these records are just becoming long enough to provide useful climatological information.

Evaporation

Plants act as wicks extending into the soil (Chapter 6), drawing water from a range of depths in the soil to the surface (in this case, the leaf surface) more rapidly than it moves through unvegetated soil. Moisture can evaporate rapidly from a leaf, which has a high surface-to-volume ratio. Air motion is usually greater away from the ground, promoting greater evaporation at the leaf surface, although the canopy itself acts to slow the speed of the wind. Evaporation from the soil surface and from leaves is referred to as evapotranspiration. Most evaporation takes place during daylight hours, especially in mid-afternoon and especially on sunny days, which tend to be not only warmer but windier than overcast days. Wind hastens evaporation, leading to much more rapid drying of the soil than would occur on quiet days. Because sunny summer days in this region can be very warm and very dry, periods of high evaporative demand tend to occur when the soil moisture is unlikely to be replenished by rain. Thus, plants are unlikely to get relief when they most need it.

Under some circumstances, often at night, the vertical temperature and moisture gradients are reversed and wind speeds are low. When this happens, water vapor will leave the atmosphere and be deposited on the surface as dew or frost.

MICROCLIMATE

Significant differences can exist between the general climate of an area and the climate experienced at the level of a seedling (Chapters 6, 8, and 16). Processes at all scales contribute to the weather and climate observed at a particular point. Local physical and biological conditions commonly exert a dominant influence upon energy flows that determine the microclimate. This is especially true in topographically diverse locations such as those found in southwestern Oregon and northern California.

Radiative Effects

We have noted that radiation is important in the transfer of energy from one place to another. The upward and downward flows of infrared radiation can each be very large during both day and night. During daylight hours, solar radiation considerably augments the infrared radiation stream flowing downward from the sky. At night, the energy available for surface processes, such as heating or evaporation, is often the result of a small difference between large streams of upward- and downward-flowing infrared radiation. On an exposed, flat area, downward radiation comes only from the sky. In a forest, canyon walls, mountainsides, foliage, branches, and tree trunks radiate downward as well. The vegetative canopy in this instance acts in some respects like a cloud, reducing the radiative loss of energy from the surface. Removal of the canopy or nearby tall trees can drastically affect the radiative energy balance in the vicinity of a seedling. The effects include more sunshine during the day (since shade has been removed) and increased loss of infrared radiation at night. Such an artificial climate change in a small area has been identified as a major impediment to successful reforestation (Chapters 6 and 8).

The slope and aspect of a site can greatly influence how much solar radiation it receives and at what time of day. With less atmospheric absorption, higher elevations receive somewhat more solar radiation than lower-lying land. The intensity of sunlight, therefore, is likely to be higher on hilltops than in nearby valleys. However, a south-facing slope will absorb much more radiation per unit area than a slope of the same angle facing north. The south side of a tree trunk absorbs more radiation than the north side. An east-facing slope will receive more solar radiation in the morning than in the afternoon, when the temperature is likely to be cooler. "Sunset" on such a slope may take place by mid-afternoon; the slope could already be cooling off while the sun is still in the sky. Conversely, a west-facing slope of the same angle will not receive significant solar radiation until the warmest part of the day, and seedlings growing on it may experience greater stress on a hot, sunny day.

On June 22, north- and south-facing slopes at an angle of 50 percent (26°34") at latitude 42°N (the Oregon-California border) receive nearly equal amounts of solar radiation (if atmospheric absorption is not considered), although the north-facing slope receives 2.2 more hours of sunshine. At the equinoxes in March and September, the north slope receives 335 ly (langleys—kg-cal/cm2), the south slope 884 ly, the east and west slopes 672 ly, and the horizontal surface 682 ly. On a south slope, the greatest annual radiation total is found for a slope of about 80 percent, which receives 28 percent more energy than a level surface.

Differences in absorbed radiation cause southern exposures to dry out more rapidly than northern exposures. Snow persists far longer on north slopes than on exposed south slopes. Throughout this region, it is common to see hills that are bare on the south side and heavily vegetated on the north side (Figure 4-3).

Surface Cover

The type of ground cover influences the radiation budget. Lighter surfaces, of course, reflect away more of the sun's energy than do dark surfaces. The reflectance of a surface is known as its albedo. The albedo of a substance is not necessarily the same in different portions of the spectrum. Fresh snow, for example, can appear blindingly white in visible light, reflecting 60-90 percent of the

Figure 4-3. Photograph showing effect of aspect on vegetation near Roseburg. South is to the right.

incoming solar radiation. Even old snow has an albedo of 30-60 percent. However, snow has the seemingly paradoxical property that in the infrared portion of the spectrum it is nearly "black", absorbing from 90 to 99.5 percent of the infrared radiation that strikes it.

As a cooling influence, snow is nearly unparalleled. A covering of snow changes the radiative properties of a surface completely. Snow reflects away solar energy by day and efficiently radiates away infrared energy by night (and also by day—infrared emission never stops). Another influence on surface reflectivity is vegetation. The seasonal march in the color of foliage and degree of leaf coverage affects the amount of solar radiation reaching the ground.

Local Wind Circulations

Generally, differences in temperature between two adjacent areas cause air movement. In this region, mountain-valley and land-water temperature contrasts often are responsible for local wind circulations. Upslope breezes are characteristic of daytime conditions. In the absence of large-scale winds, warm air rises along slopes toward ridges and mountaintops during the afternoon. When heated air rises, the slower-moving air near the surface mixes with the faster-moving air usually found above, causing the air near the surface to move faster. Thus, afternoon winds are usually substantially stronger than nighttime winds. They are also more apt to interact with prevailing large-scale flow.

At night, air near the surface cools readily, becomes more dense, and begins to flow downhill. Because such a flow appears to be "draining" the hillside, these winds are often called drainage winds. Drainage winds are very common, often quite gentle, and easy to recognize and interpret; campfire smoke serves as an excellent tracer to reveal their presence. Nighttime drainage winds are less connected to prevailing winds and are therefore usually less disrupted by them than daytime upslope winds. Mahrt (1986) has produced a comprehensive summary of nighttime influences on microclimate.

Cold, dense air tends to pool in lower elevations at night, creating frost pockets that commonly cool much more than nearby hillsides, especially under clear, calm conditions. If snow is on the ground in these depressions, or on surrounding hillsides, additional cooling can occur and temperatures can plunge to extremely low values. Conversely, since cold air tends to drain away from mountaintops, summits and ridges often remain fairly warm at night.

FUTURE WEATHER AND CLIMATE FLUCTUATIONS

Our knowledge of climatic behavior is rooted in observations steadily acquired over many years. After enough time has passed, we expect that averages from this period, and measures of dispersion of the variables about their averages, will realistically reflect long-term conditions. We can never be absolutely sure, however, that available measurements are not in some way misleading.

Because environmental variables constantly fluctuate, their time averages will fluctuate as well. Climatic statistics are thus subject to sampling error. This is especially true of data sets derived from short-term observations. In particular, values that describe central tendencies, such as means or medians, may not accurately represent long-term values if they are obtained from field experiments of only a few years in duration.

The situation is worse if estimates are needed of the probability of infrequent or rare events: for example; destructive winds, floods, droughts, heavy rains or snows, ice storms, severe cold or heat, or large hail. Engineers typically design roads, bridges, culverts, towers, buildings, heating and cooling systems, and other structures and equipment to withstand expected extremes. Professionals in nurseries and other forestry businesses similarly want to know about the prospect of rare but catastrophic events. However, shorter records are unlikely to contain a sufficient number of such events to accurately assess these probabilities. Even a relatively long record does not guarantee that all extreme events will be sampled. For example, there is a 37-percent probability that a "once-in-a-hundred-year" event will not occur in any randomly selected 100-year period, and there even remains a 10-percent probability that such an event will not be seen in a randomly selected 200-year period.

In recent years, a recognition has come about that human activity may be affecting global climate. If this is the case, we cannot necessarily conclude that observed trends in climatic variables are simply short-term excursions from a stable base state. It may be, rather, that the base state is changing, and that climatic statistics will not permanently return to their former values. The most prominent among the possible agents for global climate change are the so-called "greenhouse" gases, particularly carbon dioxide. Other factors which we understand imperfectly may be at work as well.

It is unlikely that climate changes resulting from these and other mechanisms will be uniform in space. Rather, climate change may manifest itself differently at different sites and different elevations within a region. Nonetheless, if this portion of North America warmed uniformly in all seasons in response to increases in trace gases, freezing levels, and thus average snow lines, are expected to rise. Snowmelt would come earlier, the growing season would be longer, and the likelihood of injurious high temperatures would increase. Because carbon dioxide is used by plants in photosynthesis, that process would likely take place at a higher rate in an enriched atmosphere. Discussions of these concerns and others can be found in Harrington (1987), Pastor and Post (1988), Sedjo (1989), and Franklin et al. (1992), among others. This subject is likely to receive much more scrutiny in the future.

Our ability to simulate the behavior of climate with numerical models is still in its infancy. Likewise, our ability to predict future climatic béhavior with confidence remains primitive. The spatial resolution of these models is too coarse to offer definitive conclusions about a region of the size under consideration in this book. One of the biggest difficulties is in the simulation of the precipitation process and the other factors of the hydrologic cycle. As an example, a long-term change in precipitation in one direction during the warm season, accompanied by a similar change in the other direction during the cool season, would produce no change in the annual mean but could nonetheless lead to significant impacts through seasonal processes. Progress will be slow and modest in improvement of mathematical models, especially those that will be needed to describe a region with such strong climate gradients. However, climate variability, whether its cause is natural or artificial, is integrally related to the health of seedlings and will be an important influence on survival and growth of regenerated forests.

SUMMARY

The growing seedling is subject to a wide variety of climatic influences, including wind, temperature, moisture, and solar radiation. Careful consideration of climatic probabilities can increase the chances of successful and cost-effective reforestation. Such a wealth of climatological information exists that it is not possible in one short chapter to address all the aspects of climate that may be of interest to the reforestation professional. More-powerful computers and increased storage capability have made it possible to tailor the analysis of climatic data to specific needs. Increasingly diverse arrays of data collection networks have recently been deployed. Some are managed by the National Oceanic and Atmospheric Administration; others exist to fulfill the objectives of resource management agencies such as the USDA Forest Service, the USDI Bureau of Land Management, the Army Corps of Engineers, the U.S. Geological Survey, and state and local entities. Much of the data for this chapter was taken from digital and paper archives of the Oregon Office of the State Climatologist and from publications of the National Climatic Data Center in Asheville, North Carolina. The state climatologists of Oregon and California maintain extensive records of original and summarized climatic data. The Agricultural Extension Service in California has access to additional information. Another source is the Western Regional Climate Center in Reno, Nevada.

LITERATURE CITED

CHILDS, S.W., and L.E. FLINT. 1987. Effect of shadecards, shelterwoods, and clearcuts on temperature and moisture environments. Forest Ecology and Management 18:205-217.

ELLIOTT, W.P., and R.K. REED. 1973. Oceanic rainfall off the Pacific Northwest coast. Journal of Geophysical Research 78(6):941-948.

FLINT, L.E., and S.W. CHILDS. 1983. A comparison of field and laboratory measured soil water release curves for forest soils. P. 207 in Agronomy Abstracts, American Society of Agronomy.

FRANKLIN, J.F., F.J. SWANSON, M.E. HARMON, D.A. PERRY, T.A. SPIES, V.H. DALE, A. McKEE, W.K. FERRELL, S.V. GREGORY, J.D. LATTIN, T.D. SCHOWALTER, D. LARSEN, and J.E. MEANS. 1992. The effects of global climatic change on forests in northwestern North America. P. 244-257 in R. Peters and T. Lovejoy, eds., Global Warming and Biological Diversity. Yale University Press, New Haven, Connecticut.

FROEHLICH, H.A., D.H. McNABB, and F. GAWEDA. 1982. Average annual precipitation, 1960-1980, in southwest Oregon. Oregon State University Extension Service, Corvallis. Miscellaneous Publication EM 8220. 7 p.

HARRINGTON, J.D. 1987. Climate change: a review of causes. Canadian Journal of Forest Research 17:1313-1339.

HELGERSON, O. 1990. Heat damage in tree seedlings and its prevention. New Forests 3:17-42.

MAHRT, L. 1986. Nocturnal topoclimatology. World Meteorological Organization. WCP-117, TD-132. 76 p.

McNABB, D.H., H.A. FROEHLICH, and F. GAWEDA. 1982. Average dry-season precipitation in southwest Oregon, May through September. Oregon State University Extension Service, Corvallis. EM 8226. 7 p.

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION. 1973. Precipitation-frequency atlas of the western United States. Volume X (Oregon). Volume XI (California). National Climatic Data Center, Asheville, North Carolina.

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION. 1982a. Monthly normals of temperature, precipitation, and heating and cooling degree days 1951-1980. Climatography of the United States, No. 81. California, Oregon. National Climatic Data Center, Asheville, North Carolina.

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION. 1982b. Climatic summaries for selected cities, 1951-1980. Climatography of the United States, No. 20. California, Oregon. National Climatic Data Center, Asheville, North Carolina.

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION. 1988. Freeze/frost data. Climatography of the United States, No. 20, supplement No. 1. National Climatic Data Center, Asheville, North Carolina.

PASTOR, J., and W.M. POST. 1988. Response of northern forests to CO^2-induced climate change. Nature 334:55-58.

REED, R.K., and W.P. ELLIOTT. 1973. Precipitation at ocean weather stations in the North Pacific. Journal of Geophysical Research 78(30):7087-7091.

SEDJO, R.A. 1989. Forests to offset the greenhouse effect. Journal of Forestry 87:12-15.

WADE, J.E., and R.J. WITTRUP. 1987. Analysis of extreme winds at Pacific Northwest wind energy survey sites. Wind Resource Assessment Laboratory, Oregon State University, Corvallis. Report BPA 87-24. 137 p.

WANTZ, J.W., and R.E. SINCLAIR. 1981. Distribution of extreme winds in the Bonneville Power Administration service area. Journal of Applied Meteorology 20:1400-1411.

WINSTON, M., and J. D. GOODRIDGE. 1980. Precipitation and runoff in the Smith River watershed. California Department of Water Resources, Oregon Office of State Climatologist, or Western Regional Climate Center, Reno, Nevada.

RESOURCES FOR FURTHER STUDY

Climatography of the U.S., Number 20. Climatic summaries for selected cities. Available from the National Climatic Data Center, Federal Building, Asheville, North Carolina.

Climatological Data. Published monthly for each state by the National Climatic Data Center, Federal Building, Asheville, North Carolina.

Climatological Handbook, Columbia Basin States. Pacific Northwest River Basins Commission, 1965 through 1975.
- Volume 1. Part A and Part B. Temperature.
- Volume 2. Precipitation.
- Volume 3. Part A and Part B. Hourly Data.
- Volume 4. Canadian Data.
- Volume 5. Lower Atmosphere Handbook.
- Volume 6. Part 1A and Part 1B. Lower Atmosphere Handbook.

Local Climatological Data. Published monthly for selected cities by the National Climatic Data Center, Federal Building, Asheville, North Carolina.

NOAA. 1987. Local climatological data, annual summary. Selected cities. National Climatic Data Center, Asheville, North Carolina.

Oregon Office of the State Climatologist. Climatological data. Department of Atmospheric Sciences, Oregon State University, Corvallis, Oregon.

REDMOND, K.T. 1985. An inventory of climate data for the state of Oregon. Office of the State Climatologist, Oregon State University, Corvallis. Report SCP-3. 160 p.