CHAPTER

19

THE REDWOOD FOREST AND ASSOCIATED NORTH COAST FORESTS

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INTRODUCTION

Although the coniferous forests of coastal California from the Oregon border south to San Luis Obispo Co. are characterized by a California endemic (coast redwood, *Sequoia sempervirens*), they are mainly a southern extension of the great forests of Washington and Oregon. The coast redwoods make this forest outstanding; these magnificent trees are the world's tallest (112 m), growing at rates near world maximum (42 $m^3/ha^{-1}/yr^{-1}$), with accumulations of wood mass unequaled in any other place (Fritz 1945; Roy 1966; Fig. 19-1).

There are many references in the literature over the past 100 yr describing these forests (e.g., the Whitney Survey of 1865; Jepson 1910; the Cooperative Vegetation and Soil-Vegetation Surveys of the State of California and the U.S. Forest Service; and others documented in the bibliographic work of Fritz 1957). Recently, the National Park Service, the California Department of Parks and Recreation, and the University of California have carried out ecological studies. Cooper (1965) published an account of redwood ecology in which he concentrated on the forests in commercial timber production. Becking (1968) described the ecological conditions in old redwood groves, and Stone and Vasey (1968) discussed how these can be maintained.

A major portion of the data in this chapter is derived from vegetation and soil maps and study plots of the State Cooperative Soil-Vegetation Survey (see Chapter 6) which has covered the entire north coast forest area. First the vegetation of the area will be examined, then the environmental factors that seem to be related to the array of vegetation types will be discussed, and finally certain anomalies will be considered.

VEGETATION

Vegetation will be considered in terms of the most prevalent species of conifer and hardwood trees (Table 19-1). Common names will be emphasized in the text. Some of the conifers, such as Douglas fir, grand fir, hemlock, Sitka spruce, western red cedar, and Pt. Orford cedar, extend from the moist climates of Alaska, British Columbia, Washington, and Oregon, as noted by Pavari (1958). Other conifers, such

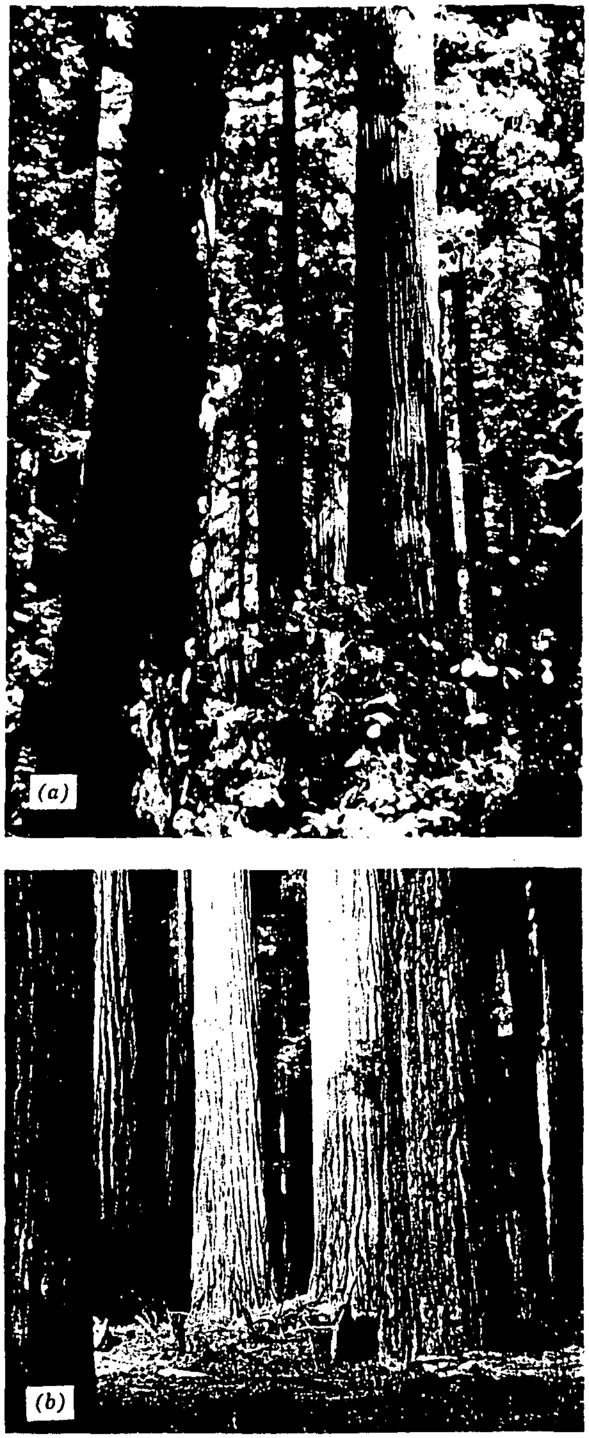

Figure 19-1. (*a*) Redwood forest near Prairie Creek, Humboldt Co. Note figure at base of tree in bottom middle foreground, for size scale. (*b*) Redwood forest on alluvial soil in Bull Creek Flat, Humboldt Co. Note the absence of trunk flaring at ground level, indicating deposition of sediment.

TABLE 19-1. Tree species of the redwood and north coastal forests and abbreviations used in text and figures

Category	Species: Common Name	Binomial Name	Symbol Abbreviation
Conifer trees	Redwood	*Sequoia sempervirens*	R
	Douglas fir	*Pseudotsuga menziesii*	D
	Grand fir	*Abies grandis*	Ĝ
	Coast hemlock	*Tsuga heterophylla*	H
	Sitka spruce	*Picea sitchensis*	S′
	Western red cedar	*Thuja plicata*	$\underline{C}$
	Pt. Orford cedar	*Chamaecyparis lawsoniana*	O
	Jeffrey pine	*Pinus jeffreyi*	J
	Incense cedar	*Libocedrus decurrens*	I
	Sugar pine	*Pinus lambertiana*	S
	Nutmeg	*Torreya californica*	N
	Yew	*Taxus brevifolia*	U
	Western white pine	*Pinus monticola*	W′
	Shore pine	*P. contorta*	L_C
	Bolander pine	*P. contorta* ssp. *bolanderi*	L_B
Hardwood trees	Tan oak	*Lithocarpus densiflora*	T
	Madrone	*Arbutus menziesii*	M
	Garry oak	*Quercus garryana*	G
	Black oak	*Q. kelloggii*	B
	Canyon oak	*Q. chrysolepis*	C
	Coast live oak	*Q. agrifolia*	A
	Interior live oak	*Q. wislizenii*	W
	Red alder	*Alnus oregona*	$\underline{R}$
	California bay	*Umbellularia californica*	L′
	Big-leaf maple	*Acer macrophyllum*	$\underline{M}$
	Oregon ash	*Fraxinus latifolia*	$\overline{O}$

as the pines, represent extensions northward from more arid areas to the south and east. Redwood is the main species indigenous to the area, and the one that distinguishes the north coastal forests of California.

In traversing these forests from moist to dry locations (as along the coast from Crescent City to Ukiah), one progresses from Sitka spruce–grand fir–hemlock in moist areas, to redwood mixed with other conifers, to redwood mixed with hardwoods, to Douglas fir–hardwoods, and finally to grassland–oak woodland mosaics in the driest situations. The zonation of forest types is complex, following both latitudinal and inland gradients. To quantify the relationships, I have compiled a series of transects by referring to soil–vegetation type maps, recording types at 1 mile (1.6 km) intervals. Figure 19-2 shows the main tree species and their occurrences along each transect.

Transects Across North Coast Forests

The northernmost transect, inland from Big Lagoon at 41°11′10″N, shows an initial very narrow coastal strip with a forest of Sitka spruce and grand fir. Redwood appears 1.6 km inland. Sitka spruce drops out within 3–4 km of the coast, but grand fir continues further inland. A tan oak–hardwood component begins 5 km inland. Redwood remains the most abundant species up to 16 km inland, but thereafter Douglas fir becomes the most abundant conifer. Hardwood forest is dominant beyond 16 km inland, with tan oak, Garry oak, and madrone predominating.

In the transect at 40°32′54″N, a Sitka spruce–grand fir–Douglas fir forest extends inland across the Wildcat Hills for nearly 25 km to the Eel River valley. Here, red alder appears as a seral stage after logging of spruce and fir. This spruce–fir forest is apparently related to a strong northwest wind exposure in the Wildcat Hills south of Ferndale. Beyond 24 km inland, redwood first appears on this transect in a wind-sheltered ravine near Rhonerville and continues as the dominant, associated with Douglas fir, to 32 km inland. Beyond this, Douglas fir is most

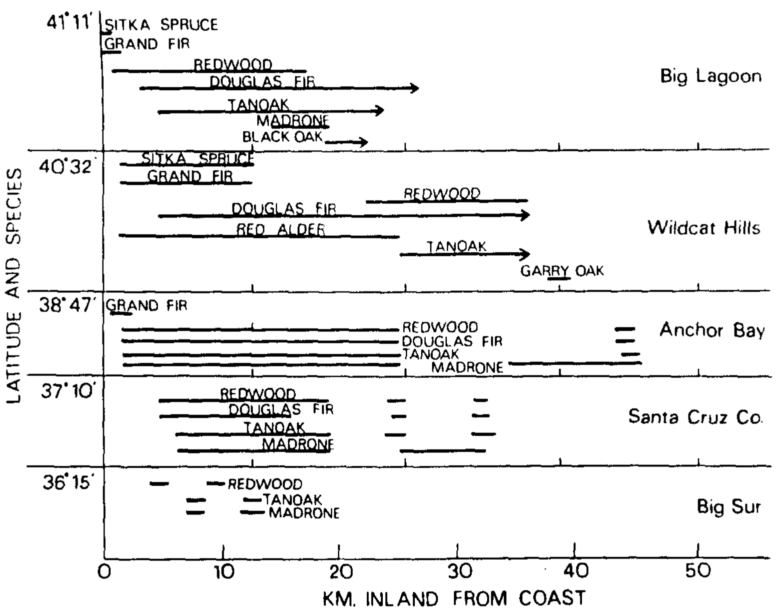

Figure 19-2. The occurrence of major tree species of north coastal forests on transects inland from the ocean at various latitudes, arranged from north to south. Arrows indicate that the species extend further inland.

abundant. There is an abrupt transition to Garry oak woodland at 39 km inland, with no redwood thereafter.

Further south, progressing inland from a point south of Anchor Bay at 38°47′36″ N, there is a narrow coastal bench with grassland and bishop pine (*Pinus muricata*), followed by a narrow 1–2 km wide strip of Douglas fir, redwood, and grand fir, with hardwoods, tan oak and madrone. Redwood continues as the major conifer until 12 km inland, after which Douglas fir predominates. Sugar pine enters the forest between 13 and 16 km from the coast. Black oak, madrone, and tan oak dominate beyond 19 km, with Douglas fir the only conifer except for an isolated stand of redwood in the Russian River canyon north of Cloverdale 37 km inland. This is the farthest inland that redwood extends in this area. Live oaks (*Quercus agrifolia* and *Q. wislizenii*) appear beyond 35 km. However, the absolutely farthest inland redwood as noted by Jepson (1910) is east of the Napa Valley near Angwin, California, in Pope Valley where, due east of Fort Ross on the coast, it would be 71.6 km (44.5 miles inland), or, at closest distance to the east of Duncan Mills, 60 km inland (36.8 miles).

Along a transect in Santa Cruz Co. at 37°10′0″ N, the first vegetation is a narrow coastal fringe of cultivated terrace land and hilly coastal scrub (*Artemisia, Baccharis*; see Chapter 21). Redwood is the main conifer from 5 to 19 km inland, with Douglas fir the only associated conifer and the hardwoods tan oak and madrone. A patch of this forest extends 32 km inland to Los Gatos Creek, but beyond 19 km it is interrupted by *Quercus agrifolia* woodland and *Ademostoma fasiculatum* chaparral, and chaparral becomes dominant beyond 32 km inland.

On a transect from Cooper Pt., Monterey Co., 36°15″0″ N, the north coastal forest is reduced to stringers of redwood in very moist canyon bottoms, such as along the Big Sur River. Hard and soft chaparral, coast live oak, tan oak, and California bay predominate. Finally, at Salmon Creek, 35°48′0″ N, redwood reaches its southern limit as a small windswept clump on the south side of a ridge a few hundred meters from the coast, surrounded by coastal sage scrub (St. John and Raymond 1930).

In summary, the redwood belt is usually only about 16 km wide, and it is not always near the coast except as one approaches its southern limit. Hardwoods (except red alder) increase with distance inland. The narrow distribution of redwood is typified in Humboldt Co. There redwood forest is 16–24 km wide, portions of it trend northwest–southeast, and there are places where the western edge is very far inland.

Successional Relationships

The progression of climax vegetation types, from wet to dry locations, is summarized in Tables 19-2 and 19-3. The grasslands, however, occur in two situations, summer moist coastal grasslands and summer dry interior grasslands. Thus the complete progression of vegetation, by broad physiognomical types, is from coastal grassland to conifer forests, to conifer–hardwood forests, to oak woodlands, and to interior grasslands. Within this is an array of shrub types, usually on shallow, eroded soils (coastal scrub, *Arctostaphylos* chaparral, *Adenostoma* chaparral), and some miscellaneous types often on unusual parent material such as serpentine rock, or

TABLE 19-2. Vegetation type groups in the north coastal forests of California

Physiognomy	Type	Dominant Species
Conifer forest	Fir-spruce	Ĝ, S´, H
	Redwood-fir	R, Ĝ
	Redwood-Douglas fir	R, D
	Redwood	R
	Douglas fir	D
Conifer-hardwood forest	Redwood, Douglas fir, tan oak, madrone	R, D, T, M
	Douglas fir-hardwood	D, T, M, D, G
Hardwood forest	Oak woodlands	G, B. T
Shrub	Baccharis-coastal scrub	Baccharis, Garrya, Ceanothus
	Manzanita-chamise	Adenostoma, Ceanothus
Grasslands and fern prairie	Acid coastal grasslands	Aira, Elymus, Danthonia, Rumex, Pteridium
	Interior grasslands	Bromus, Elymus
Miscellaneous	Pine-cedar-cypress pygmy forest	J, I, Cupressus sargentii, Arctostaphylos viscida
	Redwood, sugar pine, hardwood	R, D, S, T, M

acid coastal plain deposits (*Pinus jeffreyi, P. lambertiana, Libocedrus decurrens, Cupressus* species, pygmy forest).

In addition to this gradient of climax types, mosaics of seral stages follow logging, fire, windthrow, landslide, sand encroachment, and other disturbances. The following are examples of some seres, based on evidence from vegetation types mapped in the field.

Grand fir–Sitka spruce–Douglas fir. Fir-spruce forests are found in greatest extent in the Wildcat Hills between the Bear River ridge and the Eel River, south of Ferndale. The vegetation was mapped by Colwell et al. (1959a,b). In the southwest corner of Township 2N, Range 2W (Humboldt Base and Meridian), in the Guthrie Creek watershed, almost all of the seral stages following disturbance of fir-spruce forest can be found. The apparent sequence is summarized in Fig. 19-3 and below.

Logging of grand fir (Ĝ), Sitka spruce (S^1), and Douglas fir (D), with some western red cedar (*C*), results in a pioneer stage dominated by bare ground (Ba),

TABLE 19-3. Vegetation in the overstory and understory of forests representing various vegetation types in the north coastal forest area. From selected plots and plot data of the State Cooperative soil-vegetation survey

Vegetation Type	Quadrangle and Plot	Mean Annual Rainfall (mm)	Mean Temperature (°C) Ann.	Jan.	July	Species (for trees, see Table 19-1)	Overstory Cover %	Overstory Max. Height (m)	Understory Cover %	Understory Max. Height (m)
Sitka spruce-Fir (cutover)	9A2 #1	2032	11.5	7.7	15.3	S	20	30.5		
						Ĝ	< 5	0.6		
						Rubus vitifolius	15	1.2		
						R. spectabilis	15	1.8		
						Polystichum munitum	15	0.9		
						Epilobium angustifolium	15	1.2		
						R	10	13.7		
						Pteridium aquilinum	< 5	0.6		
						Misc. herbs	< 5	0.6		
Redwood-Fir	9A4 #2	2083	11.7	7.8	15.6	R	70	76.2	5	4.6
						Polystichium munitum	...	...	70	0.9
						Vaccinium ovatum	...	...	5	0.9
						V. parvifolium	...	...	5	1.8
						D	5	38.1	...	...
						Ĝ	5	38.1	...	...
						H	5	38.1	5	22.9
Redwood-Douglas fir-Hardwood	61C4 #3	1321	11.1	9.4	13.9	R	50	36.6	...	7.6
						M	20	15.2	...	...
						T	20	15.2	5	2.4
						Barren	...	...	60	...
						Myrica californica	...	...	5	1.8
						Vaccinium ovatum	...	...	5	0.9
						Gaultheria shallon	...	...	5	0.3
						Polystichum munitum	...	...	5	0.6

Pteridium 5 0.6

						Polystichum munitum	...	...	5	0.6
						Pteridium	...	...	5	0.6
						Rhus diversiloba	...	...	5	0.6
						D	5	36.6	...	...
Douglas fir-hardwood	26C2 #4	1575	12.2	5.0	20.0	D	50	61.0	...	...
						T	20	24.4	50	9.1
						M	20	21.3	...	...
						Berberis nervosa	...	...	10	0.6
						M	...	...	10	12.2
						Vaccinium ovatum	...	...	10	0.9
						Polystichum munitum	...	...	10	0.6
						L´	10	18.3	...	...
Hardwood (Garry oak woodland)	26B1 #16	1829	11.7	3.9	20.6	G	100	15.2	10	9.1
						D	...	...	10	1.5
						Holodiscus discolor	...	...	10	0.9
						Rosa spp.	...	...	5	0.6
						Prunus emarginata	...	...	5	0.6
						Polystichum munitum	...	...	5	0.3

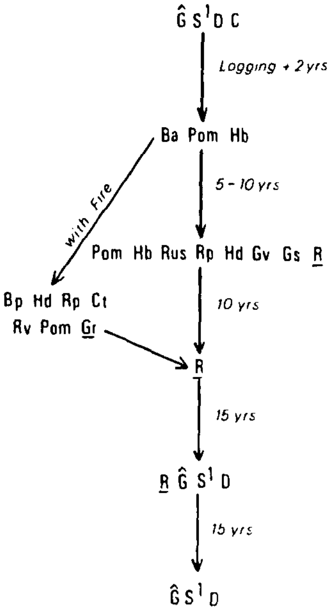

Figure 19-3. The seral stages in the grand fir-Sitka spruce forests after timber harvest in the Wildcat Hills southwest of Ferndale, Humboldt Co., at latitude 40°32′N.

Polystichum munitum (Pom), and various herbs (Hb). These herbs are usually composites with light seeds such as *Erechtites arguta* and *E. prenanthoides*. After 5–10 yr, *Polystichum* and herbs are still abundant, but a large number of shrubs have entered: *Rubus spectabilis* (Rus), *R. parviflorus* (Rp), *Holodiscus discolor* (Hd), *Garrya veatchii* (Gv), and *Gaultheria shallon* (Gs). Details of the species present immediately after logging have been presented by Roy (1966). Some red alder seedlings (*R*) begin overtopping the brush, and by another 10 yr (15–20 yr after the disturbance) red alder dominates the site but conifer seedlings appear beneath it. Over the course of the next 30 yr, these conifers (fir, spruce, Douglas fir) overtop the red alder and replace it, resulting in the climax community. If the pioneer community is burned, as it would be in preparation for a pasture, a slightly different sere results. *Baccharis pilularis* (BP), *Holodiscus discolor* (Hd), *Ceanothus thrysiflorus* (Ct), *Rubus vitifolius* (Rv), sword fern (Pom), and various grasses occur. Repeated burning ultimately produces a pasture with clumps of sword fern, but when burning ceases, red alder comes to dominate and conifers reinvade. More intense fires result in dominance by *C. thrysiflorus*.

Redwood–grand fir. Redwood–grand fir forest progresses through a similar sere after logging or windthrow. Examples of all stages can be found just east of Big Lagoon, where the vegetation was mapped by DeLapp et al. (1961) in quadrangle 10D1. The sere is shown in Figure 19-4 and is summarized below.

A pioneer community of bare ground (Ba), herbs (Hb), and sword fern (Pom) is followed within 10 yr by bracken fern (Pta), herbs (Hb), sword fern (Pom), redwood sprouts (R), *Baccharis pilularis* (Bp), and *Rubus* spp. (*Rx*). About 30 yr later, redwood again dominates the site and grand fir has overtopped the brush, but a few *Rubus spectabilis* and *R. parviflorus* shrubs remain. By 60–70 yr from the time of disturbance, the redwood–grand fir forest has returned. Redwood returns first

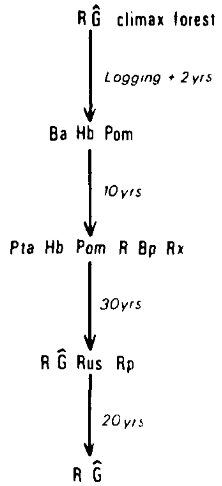

Figure 19-4. The seral stages in vegetation composition in the redwood–grand fir forest after timber harvest in an area immediately east of Big Lagoon, Humboldt Co., at latitude 41°10′N.

because of stump sprouting, whereas the other conifers depend on seed and return more slowly. Sitka spruce and western red cedar may also appear in this type. Stone and Vasey (1968) believed that redwood itself represents past disturbance such as fire, and that if fire is kept out a potential climax species is western red cedar.

Conifer–hardwood. The conifer–hardwood forests progress through a similar sere, as can be described from the vegetation mapped by Cuff et al. (1949) in the southeast quarter of the Branscomb quadrangle (44D4). The sere is shown in Fig. 19-5 and is summarized below.

After the climax forest, with redwood (R), Douglas fir (D), tan oak (T), and madrone (M) is logged, the pioneer community is dominated by *Erechtites* spp., *Whipplea modesta*, and sprouts of tan oak, madrone, and redwood. Seedlings of Douglas fir soon appear. The sprouting hardwoods dominate within 4–8 yr, but in another 15 yr a fairly tall stand of hardwoods and conifers results. By 70–85 yr after disturbance, redwood and Douglas fir have overtopped the hardwoods and the

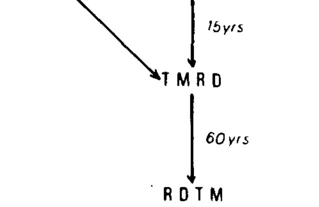

Figure 19-5. The seral stages in the redwood–Douglas fir–tan oak–madrone forest after timber harvest disturbance in an area along the south fork of the Ten Mile River, Mendocino Co., at latitude 39°33′N.

original community has returned. If fire occurs at any time, the sere is shunted to a *Ceanothus*-dominated stage (*C. thrysiflorus* or *C. velutinus*).

In addition to these seres which come after disturbance, there is a general increase in young stands of Douglas fir in the region, with age classes from 50 to 75 yr. These are invading either grassland areas near the coast or Garry oak forests in the interior. An example of an area with extensive invasion of grasslands is just south of the mouth of the Mattole River. In the sequence which occurs on grassland soils of the Wilder soil series in the first few kilometers east of Punta Gorda, the grassland is invaded by bracken fern, and this in turn by even-aged Douglas fir regeneration, which then takes over the grassland as a uniform stand of Douglas fir (Colwell et al. 1958). Similar Douglas fir invasions into grass openings have been observed throughout the northern coastal forest area.

The invasion of interior oak forests is typified in the area near Bridgeville, where Garry oak–black oak forests on Tyson soil series are gradually invaded by an understory of Douglas fir. In time these become oak–Douglas fir forests, with the Douglas fir gradually crowding the oaks to make pure young Douglas fir stands with an understory of oaks which gradually die out. This was noted on the areas at the head of Larabee Creek and near Bridgeville by Colwell et al. (1958). It has also been observed near Schoolhouse Peak in the Redwood Creek drainage and in the area north of Round Valley in Mendocino Co. The factors bringing this about may be cessation or lessened use of fire to keep grass openings and woodlands open, or a climatic change, or the occurrence of particular years favorable for Douglas fir regeneration. Many of these stands have been harvested since the area was mapped.

Climatic Relationships

The climatic variables influencing redwood forest have long been thought to be related to summer fog and a maritime setting. Figure 19-6 summarizes temperature along transects running from the coast inland. Temperature extremes generally

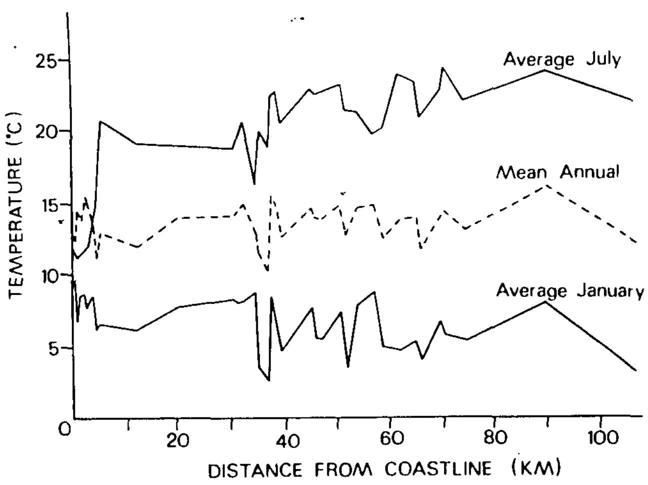

Figure 19-6. The mean annual temperatures, mean July and January temperatures, and distances inland from the coastline, based on data from 33 climate stations in the north coastal area of California. From data of W. L. Colwell, California State Cooperative Soil–Vegetation Survey.

increase with distance inland because of increasing elevation. However, topographical factors add to this, with interior valleys having broad ranges of temperature, from high maxima in summer to low minima in winter. It is apparent that position relative to the coast controls the gradient of increasing maximum temperatures and, to a lesser degree, minimum temperatures, resulting in the wider range of temperatures as one proceeds inland. In growth chamber studies, Hellmers and Sundahl (1959) found that redwood has very little thermoperiodism and thus does well in a stable temperature regime. Also they reported an optimum temperature for redwood seedling growth of 18.9°C. This is supported by Kuser (1976), who found optimum site quality or productivity of redwood to occur at a mean summer temperature of 17.8°C.

The wind patterns in the area and the influx of marine air, particularly during the summer, are partly the result of this heating of the inland areas during the summer, and the influx of marine air, as into a furnace. There is a pattern of such inflow of marine air up the Eel River canyon, as indicated by the windflagging of trees at various places in the redwood forest and adjacent forest types in the area. The influx of marine air seems to be related to the distribution of the redwood forest. Immediately along the coast, where the incoming wind is high in salt spray aerosols, there is a grassland strip, or forest area with trees that are tolerant to salt spray damage, such as Sitka spruce and Douglas fir. It is only inland of this effect that one begins to see a redwood forest, which extends inland until the marine air influence is overcome by inland heating of the land. The anomaly of the large gap in the redwood forest that occurs in the Mattole River basin seems to be related to a large back eddy in the summertime wind pattern. As the prevailing wind across the ocean (NW 18°) sweeps past the Kings Peak Range, there is actually an offshore wind pattern across the Mattole River basin, resulting in very dry downdrafts along the face of the Kings Peak Range. Related to this is a broad area of grassland and oak woodland in the Mattole River valley, despite the fact that the overall annual precipitation is the highest in the redwood region.

The generalization that one can make regarding wind and the distribution of vegetation types along the north coast is that, where the influx of marine air is excessive, there will be a coastal grassland, as along much of the coast from Eureka south, and inland in wind gaps such as those between Bodega Bay and Petaluma, the Golden Gate, and the Salinas Valley. Associated with the marine air influx is the occurrence of summer fog, which results in fog drip. Azevedo and Morgan (1974) have shown amounts of fog drip ranging from 18.4 to 30.4 cm. Of course, these effects will be interwoven with other factors which tend to favor or to mitigate against the presence of redwood forest or other forest types.

Topographical Relationships

Topography across the north coastal forest area shows an increasing elevation inland, dissected by deep valleys. This increase in elevation may be very abrupt, as in the Kings Peak Range at 40°10′N, where within 5 km of the ocean the elevation is 1246 m. Instead, the rise may be gradual, as near Ft. Bragg at 39°25′N, where the coast mountains crest at 1034 m nearly 40 km inland of Pine Ridge west of Ukiah. The rivers of the area have cut into these mountain ranges along fault alignments which tend to parallel the coastline and the San Andreas Fault. Thus the interior valleys trend from southeast to northwest. This tends to accentuate the inland climatic aspects of some of the interior valleys in their headwaters areas, isolating them from the coastal climate although they are only a short distance inland. As a result, one finds gaps in the range of species such as redwood which depend on the more equable marine climate. On the other hand, where the valleys open toward the ocean so as to reinforce the summer marine air indraft with its prevailing flow from the northwest, as at the mouth of the Eel River, the redwood belt extends further inland.

As one progresses inland, the climate becomes more severe because of extremes of summer heat and low humidity. The topographical effect of north slopes and of long slopes as sources of seepage water in their lower reaches becomes of more importance. Thus, in the upper south fork of the Eel River near Leggett Valley, the main extent of redwood forest ends abruptly with a general change from northerly to southerly slopes. Waring and Major (1964) reported details of the effects of altitude on the distribution of vegetation types on Grasshopper Peak in Humboldt Redwood State Park. Grasshopper Peak carries a range of vegetation types from nearly pure redwood forest at its base in Bull Creek at an elevation of 37 m to grasslands and Douglas fir–hardwood stands on Grasshopper Peak at 1070 m. Generally, they attributed this gradient of vegetation to the increasing dryness of the sites with increasing elevation.

Geological Relationships

The geology of the north coastal forest area in terms of the major rock types and the soils derived from them plays an important role in determining vegetation and the abrupt boundaries to some vegetation types.

The geological types trend in a manner similar to the topography of the area. Thus the topographical, geological, and soil controls on vegetation distribution reinforce each other. The rocks of the area are predominantly sedimentary. Younger, less consolidated sedimentary rocks near the coast give rise to deeper soils with greater water-holding capacities than those farther inland from older and harder sedimentary rocks. Coastal terraces adjacent to the coastline often have very old surfaces with old, infertile soils, and on these occurs the depauperate vegetation of pygmy forest types (*Pinus contorta* ssp. *bolanderi*, *Cupressus pygmaea*), as described by Gardner and Bradshaw (1954); see also Chapter 9). There are abrupt boundaries of these pygmy forest areas where erosion has cut into underlying rock types to expose younger, more fertile soils, on which the north coastal redwood and Douglas fir forests do better (Jenny et al. 1969).

Intrusions of serpentine and peridotite rock trend across the north coastal area from southwest to northwest, forming soil anomalies that are high in magnesium and low in potassium, calcium, and phosphorus. Frequently in contact with these are metamorphic rocks such as glaucophane schists weathering to heavy clay soils with high magnesium contents supporting grassland vegetation. The serpentine and peridotite areas themselves have anomalous vegetation for the area. An example of such is Red Mt. in northern Mendocino Co. The forest on the serpentine area consists of conifers only, with *Pinus jeffreyi*, *P. lambertiana*, *P. ponderosa*, *P. attenuata*, *Cupressus sargentii*, *C. macnabiana*, and *Calocedrus decurrens*. The lack of hardwoods seems attributable to the low soil fertility. This coniferous forest has an abrupt boundary with the more typical Douglas fir–hardwood forest on adjacent soils derived from sedimentary rocks that are more typical of the area. Thus one could conclude that the "climax" vegetation of this north coastal forest would be entirely different if by chance the geological factor were different; one would probably find a mixed conifer forest with very few hardwoods if the country rock had been all peridotite instead of the present sedimentary rock.

The boundary of the main redwood belt often ends abruptly at a change in rock type. An example of this occurs at Jedediah Smith Redwoods State Park on soil-vegetation quadrangle 9A4, classified and mapped by DeLapp and Smith (1976). The conifers on the soils derived from sedimentary rock are *Sequoia sempervirens, Pseudotsuga menziesii,* and *Tsuga heterophylla,* with infrequent *Chamaecyparis lawsoniana.* However, on the adjacent soils derived from peridotite rock, there is an abrupt change in vegetation within a few hundred meters. On these intrusive rocks, there is no redwood and the coniferous species are Douglas fir, Port Orford cedar, Jeffrey pine, knobcone pine, and western white pine. Some species such as Port Orford cedar, which is usually a serpentine endemic in northern California, cross this boundary, but others (e.g., western white pine and Jeffrey pine) stay strictly on the serpentine and peridotite rock. Exceptions occur where alluvium from the intrusive rocks is deposited downstream along benches on the Smith River; it supports species of both the redwood forest and the more interior mixed conifer forests.

The glades or grassland openings that often occur in the north coastal forest area are frequently vegetation anomalies related to soils derived from rocks richer in basic elements. These soils often are higher in clay content and pH than the adjacent soils from the less basic rocks that form the basis for the regional forest climax. It was noticed in mapping vegetation that ecotones of such natural grass openings with adjacent redwood, Douglas fir, or hardwood forests often resembled the sequence of vegetation types found east of the main redwood forest. The grass openings are surrounded by a margin of Douglas fir–hardwood, or of oak-hardwood that grades into Douglas fir, redwood-hardwood, and then the redwood-Douglas fir-tan oak-madrone forest typical of the area. In some areas, the inland side of the redwood forest terminates abruptly with a geological boundary that produces high-pH heavy clay grassland soils, which the redwood does not invade. Such is the case with the eastern boundary of the redwood forest on the slopes alongside the Van Duzen River just west of Bridgeville. Here, as with serpentine intrusions, the redwood ends abruptly.

Another local exception in the vegetation composition related in part to geology is the superlative redwood groves that occur on deposits of recent alluvium along the major rivers in the north coastal forest area. These form the redwood forests which laymen think of as typical redwood forests, although, in fact, they are only a small proportion of the area of the region. However, their uniqueness requires a thorough examination of their vegetation dynamics.

DYNAMICS OF REDWOOD FLAT COMMUNITIES

The life history of the superlative redwood groves along the rivers in the north coastal forest is tied into the dynamic regime of river flooding, sediment deposition, and soil buildup.

In Bull Creek Flat there is a stand of trees slightly more than 92 m tall growing on such a soil. In excavating this soil to more than 9 m depth, I found the soil profile shown in Fig. 19-7. A series of dark, organic-matter-rich layers at various depths indicated that soils were buried by subsequent sediment deposits. Below the lowest layer was a bed of stream gravels. The top layer, designated as I, was deposited during the flood of 1955, and it is evident that each of 15 layers below this represented at least 15 flood deposits. Charcoal deposits were associated with each of the layers, indicating that a fire–flood sequence may be associated with these groves. Dating of the charcoal from the lowest layer indicated an age of approximately 1000 yr. A tree that fell from an undercut bank nearby was, as determined from ring counts, 958 yr old, indicating that the forest itself was roughly the same age as the total sediment deposit. In addition, the flooding affected the ring growth in such a way as to allow a dating of the major floods that had occurred during the life of the tree. These floods occurred at intervals of 30–60 yr.

During work at Stephens Grove in Humboldt Redwoods State Park, I observed that each new deposit of sediment created ideal conditions for seed germination and seedling survival, and that the forest came in as even-aged waves of seedlings, dating the time of sediment deposition. These seedlings may end up as suppressed dwarfs because of lack of light if they are in the interior of a dense grove, or they may grow very rapidly if at the edge of a grove. Thus each of the sediment deposits may have an age class of trees associated with it, and at the margin of the grove with good light conditions these trees may be already 61 m tall, but where light conditions are poor within the stand, they may be less than 10 m in height. Many of the superlative groves have a margin of young growth seedlings now more than 100 yr old, dating the 1861 flood.

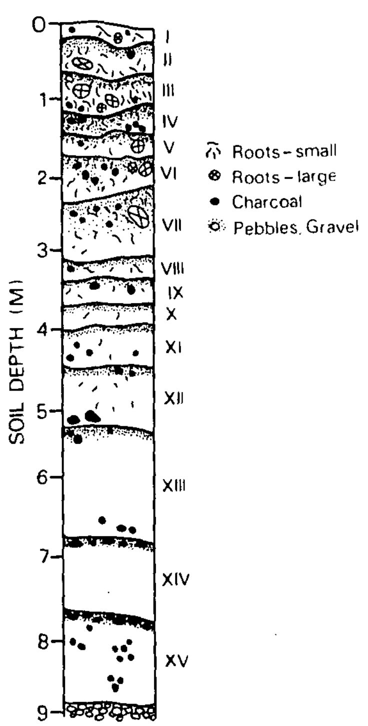

Figure 19-7. Soil under old redwood grove in Rockefeller Forest on Bull Creek Flat, showing sediment deposition layers from past floods. Layer I is from the 1955 flood, and layer XV is apparently the initial sediment layer on which the forest became established about 1000 yr ago, based on radiocarbon dating of coarcoal in the layer, but also coincident with tree ring ages for the forest.

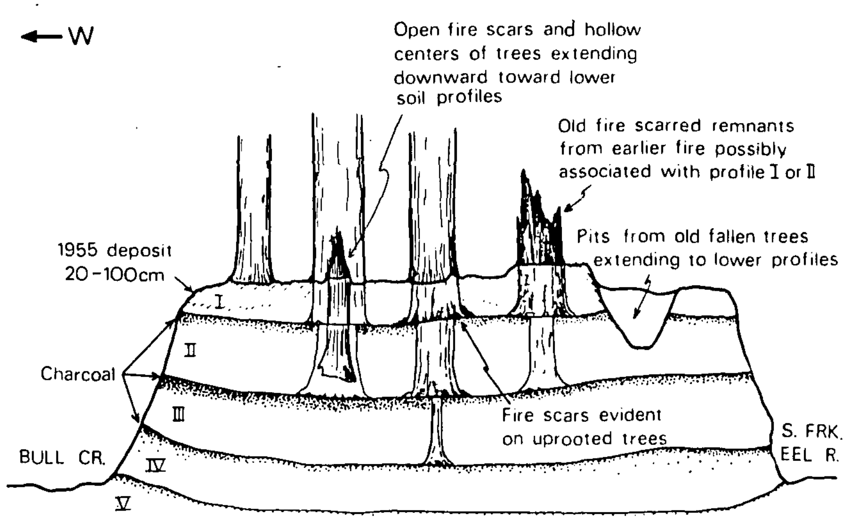

Figure 19-8. An old stand of redwood trees on Rockefeller Forest, Humboldt Redwoods State Park, in relation to various sediment deposition layers. Note multiple-layer root systems and their relation to buried soil layers, open fire scars, tree hollows extending to lower layers, consistent with old soil surface at time of fire, and pits where trees were burned out to lower soil layers.

This dynamic situation of continuous flooding and sediment deposition means that the understory species have to adapt to the same problems of new and rising soil surfaces. Stone and Vasey (1968) found that understory herbs such as *Oxalis oregona,* which typify a redwood grove understory after a long period of no disturbance, recover from deep sediment deposition by growing vertical shoots from their submerged parts, and gradually recolonize the surface. In addition, they found that the redwood itself grew roots into the new soil deposit.

Thus, as documented by Fritz (1933) at Richardson Grove, each time a new layer of soil is deposited on the alluvial flat, the tree grows a new set of surface roots corresponding to the new soil surface, giving the tree a multistoried root system corresponding to these buried layers. In addition, the broad outward taper at the lower base of the tree is buried, and the tree plunges directly into the soil. The new soil may be nutritionally important to continued good redwood growth (Florence 1965). Older trees that date back to deeply buried sediment layers may be burned out by fire, producing fire scars that open the interior of the tree trunk to the buried soil layers below; when a tree falls or burns out completely, a pit may develop down to lower soil layers. Thus one finds in a very old grove a scene as sketched in Figure 19-8. Each tree or the wreckage of past trees extends down to the flood deposit in which its major root system occurs. Research at Redwood National Park is further documenting the importance of flood and fire (see, e.g., Veirs 1975).

AREAS FOR FUTURE RESEARCH

Despite the fact that there is now a complete record of the distributions of the various vegetation types and dominant species in the north coastal area of California, there are many gaps in knowledge. Much remains to be learned about the history of these vegetation types and the changes presently occurring in them. There needs to be more study of the autecological requirements of the various species that comprise this forest vegetation. For example, most of the coniferous forest species are at the southern limit of their ranges in this portion of California, representing the southern limit of the great coniferous forest of the Pacific Northwest. Presumably this is related to the greater aridity and warmer temperatures that occur at this transition to oak woodlands and grasslands to the south and to the interior. Are these limits due to occasional extremes of drought, or to gradients of increasingly limiting average moisture? At what points in the life cycles of the species concerned are the factors limiting: is it seedling survival that is critical, or overall growth in relation to competitive advantage?

It is obvious in the case of some species that they can grow vegetatively far outside the limits of this forest area, as, for example, in the case of redwood trees planted at Stanley Park in Vancouver, B.C. Why does redwood have such abrupt boundaries in its range now, and why are these sometimes limited by geological and soil factors, and sometimes apparently by climatic factors? How do these factors interact in the limits of the range of any particular species? Does the present ecotone of the redwood forest indicate that it is extending its range again, or is it still retreating? What is the role of past fire in the present distribution of these species and the forest types that their mixtures create? What is the effect of changes brought about by human activity in these forests, as by use of fire or its control, or in the intermittent harvest of forests for timber production?

There is, in addition, an imposing conservation problem that will continue into the future. Redwood forest is estimated to have covered 800,000 ha 150 yr ago (Stone et al. 1972; Leydet 1969). Today less than 5% of this virgin redwood forest is left, and only half of that is in protected park land. Moreover, protected stands which occupy only the lower slopes of watersheds can be endangered by the activities of private developers above them, so the degree of protection is relative at present. In addition, it is possible that redwood stands will not maintain their population sizes without natural or managed fire and flood cycles. It may be necessary to develop a 500–1000 yr management plan for these parks if they are to remain well into the twenty-first century.

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