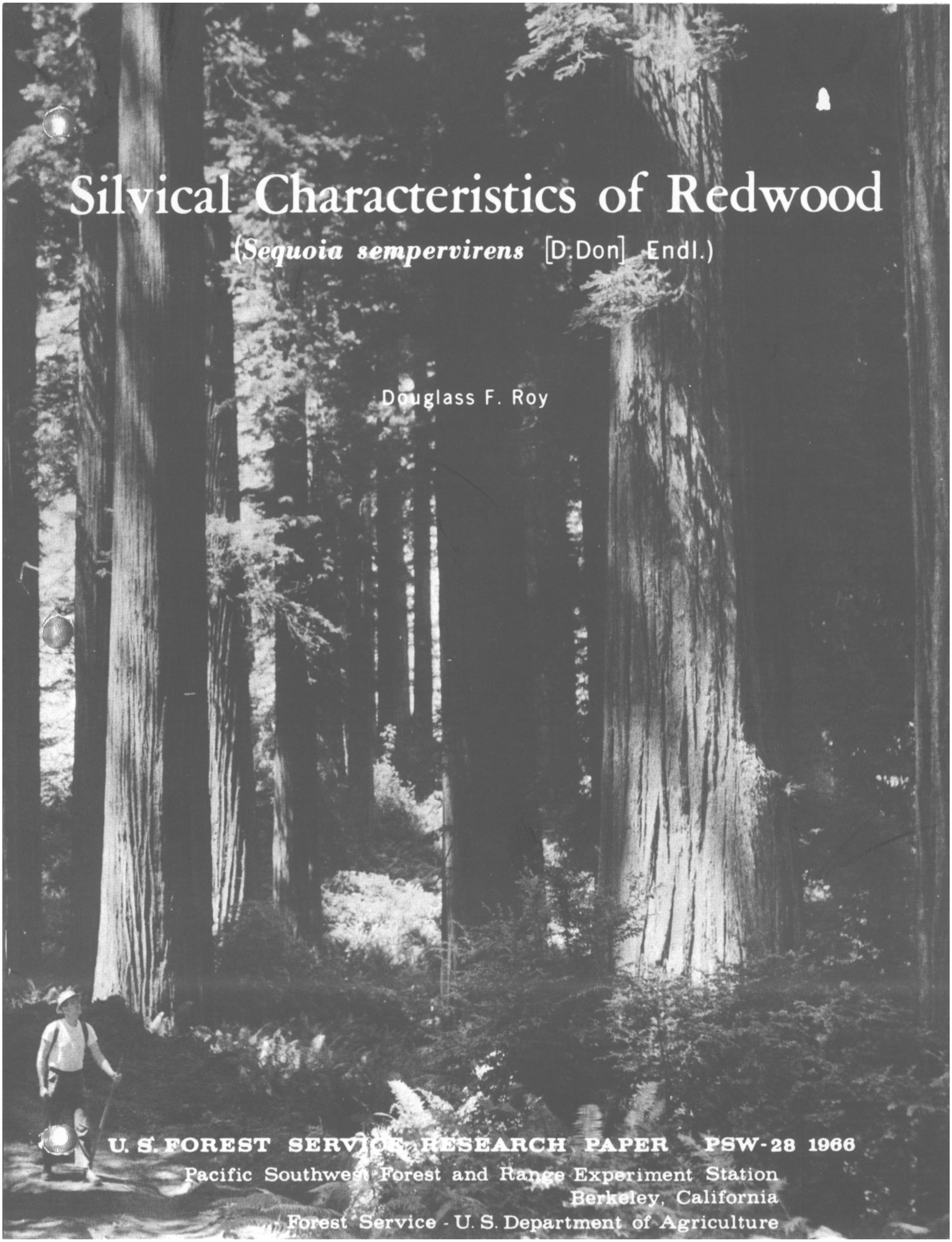

Silvical Characteristics of Redwood

(*Sequoia sempervirens* [D.Don] Endl.)

Douglass F. Roy

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Contents

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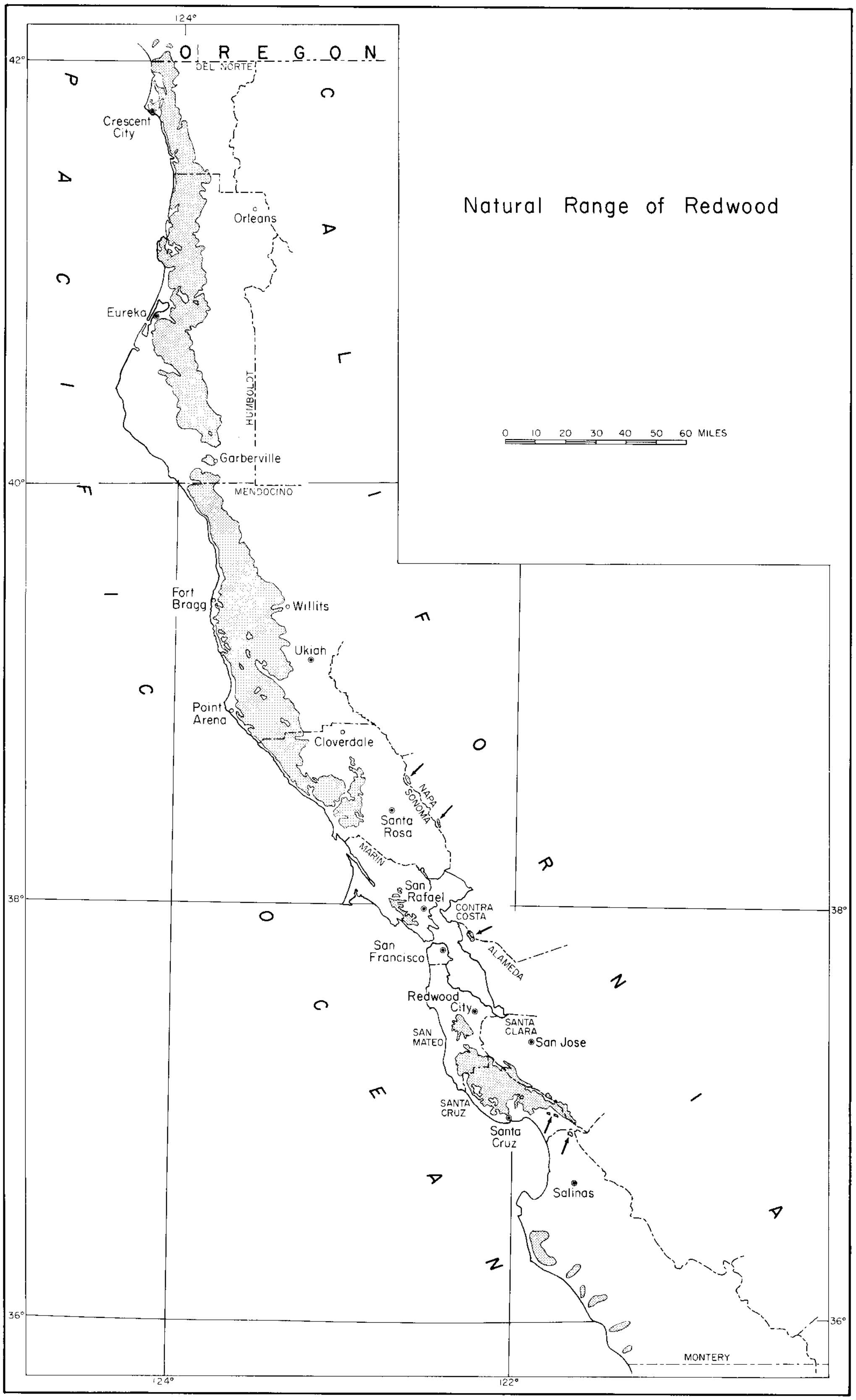

Figure 1. — *The natural range of redwood.*

The first record of redwood (*Sequoia sempervirens* [D. Don] Endl.) was written by Fray Juan Crespi on Tuesday, October 10, 1769, in his diary of the Don Gaspar de Portola Expedition. On that day the expedition traveled northwestward from a camp on the Pajaro River, now the boundary between Santa Cruz and Monterey Counties, into low hills, well forested with very high trees of a red color. No one recognized these trees so they were named redwood (palo colorado) from their color.

Archibald Menzies, surgeon and botanist with the Vancouver Expedition, is credited with the botanical discovery of redwood. He probably saw this tree at one or more points on the California coast in 1792 or 1793, but his collection is dated 1794 (Jepson 1923).

Stephen Endlicher, the noted Hungarian botanist, named the genus and the species in 1847. Although he did not explain the origin of the generic name, it seems certain that it honors the Cherokee Indian, Sequoyah, or George Guess. Sequoyah was talented, active, and prominent in working for his tribe, and is best known for developing an 83-character syllabic alphabet for the Cherokees (Jepson 1910; Save-The-Redwoods League 1935).

The natural range of redwood extends southward from two groves on the Checto River in the extreme southwest corner of Oregon to Salmon Creek Canyon in the Santa Lucia Mountains of southern Monterey County, California. This redwood belt is an irregular, narrow coastal strip about 450 miles long and 5 to 35 miles wide.1 It has a transverse break along the headwaters of the Mattole River in southern Humboldt County. And south of Sonoma County, redwoods are found in detached and irregular areas (fig. 1).

Habitat Conditions

Climatic

The mild climate of the redwood region with its equable temperatures can be classed broadly as superhumid or humid (Thornthwaite 1941). Mean annual temperatures vary between 50° and 60° F. Differences between mean annual maximum and mean annual minimum temperatures range from 10° to 15° F. for coastal points to 30° F. for the eastern edge of the redwood type. Temperatures rarely fall below 15° F. or climb above 100° F. The frost-free period lasts from 6 to 11 months (Person 1937; U. S. Forest Service 1908).

Annual precipitation varies between 25 and 122 inches and falls mostly as winter rain, although the highest ridges sometimes are covered with snow. The distribution of precipitation at Scotia, Humboldt County, by seasons is: winter, 55 percent; spring, 23 percent; summer, 2 percent; and autumn, 20 percent. Generally, January is the wettest month, and August is the driest (Martin and Kincer 1934).

The frequent summer fogs which blanket the redwood region seem to be more important to redwood than the amount of precipitation. Fog decreases water loss from evaporation and transpiration and adds to the soil moisture supply to some degree. The relationship between redwood and fog seems intimate because the natural range of this tree is limited to the regions where heavy summer fogs from the ocean provide a humid atmosphere (Cooper 1917).

[1] By Forest Survey definition, which classifies a forest stand as redwood type if redwood trees comprise 20 percent of the stand, including hardwood and conifer cover, the commercial forest land area in redwood type totals 1.6 million acres.

Edaphic

The parent rock material of the redwood region is largely massive marine sandstone formed in the Tertiary and upper Mesozoic periods. Considerable shale and lesser amounts of Mesozoic limestones and Franciscan slates, cherts, limestones, and sandstones also are represented, and schists are fairly common in some localities (Person 1937).

Soils vary from thin rocky loams on some of the steepest slopes to deep sandy loams on flats and benches. Sometimes clays are close to the surface and clay loams replace the more typical loams and sandy barns. One characteristic soil is moderately deep sandy loam containing a variable admixture of fine to coarse rocky material, usually sandstone, with a clayey subsoil (Person 1937).

Productive soils for redwood are the Hugo, Josephine, Melbourne, Empire, Sites, and Larabee series, and associated alluvial soils. The residual soils of high site quality have been derived from either consolidated or soft sedimentary rocks. They are light grayish brown or light reddish brown to brown in color, and are moderately to strongly acid (Gardner 1960; Roy 1957). Redwood tolerates a soil pH between 5.0 (acid) and 7.5 (alkaline), with 6.5 as the optimum (Zinke 1964). Soil textures grade through loam, sandy loam, fine sandy loam, silt loam, to clay loam (Gardner 1960; Roy 1957).

Limits of redwood forests sometimes are determined by soil types. For example, redwood does not grow on soils having high amounts of magnesium and sodium (Zinke 1964).

Fertility of soils under redwood stands has been studied by measuring the replaceable calcium concentration, expressed in equivalents, present in a square meter to a depth of 30 cm. This measure indicates fertility best because it separates nutritional properties from other environmental effects. Equivalents ranged from 4 to over 80, with 63 appearing to be optimum (Waring and Major 1964).

Excess nitrate formation has been found under mature redwoods bearing symptomatic silvery-gray foliage. A nitrate deficit was observed under chlorotic young-growth stands. Here, nitrification was blocked, probably because too many microorganisms were produced in the abundant organic matter resulting from timber harvesting (Florence 1965).

Basal area of redwood stands, used as an index of stand development, has been related to the lowest amount of soil moisture available during the year. This minimum available moisture, expressed as a percentage of storage capacity, ranged between 18 and 86, with 62 correlated with maximum basal area (Waring and Major 1964).

Physiographic

Redwood stands are largely confined to coastal topography between latitude 35° 41' N. and 42° 09' N. Much of the land configuration is characterized by irregular ridges oriented northwest to southeast with deep, narrow valleys between (Poli and Baker 1954). Consequently, the principal streams drain to the northwest.

Although this mountainous area is still developing by fold-faulting (Hinds 1952), the topography is characteristic of early maturity in the fluvial erosion cycle. Much of the terrain is rough, steep, and extremely dissected both by major streams and smaller drainages (Roy 1957). In spite of the rugged terrain, the total relief is small for a mountainous country. Only occasional peaks reach elevations of 4,000 to 4,500 feet above sea level.

Redwoods grow from sea level to about 3,000 feet (Jepson 1910), but most are found between 100 and 2,500 feet (Person 1937). The best stands have developed on the flats and benches along the larger streams, on moist coastal plains, river deltas, moderate westerly slopes, and valleys opening toward the sea. Some of the flats and benches support pure redwood stands of almost unbelievable volumes (Person 1937).

Although the main bodies of redwood are close to the ocean, redwood does not tolerate ocean winds. And considerable evidence suggests that it is sensitive to ocean salts carried inland during storms (Jepson 1923). Where redwoods grow close to the coast line, they are either protected from wind by other species such as Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) and Sitka spruce (*Picea sitchensis* [Bong.] Carr.), or by the landform (Zinke 1964).[2] The slopes, canyons, or valley floors where redwoods grow, are at least moderately sheltered from the direct impact of ocean gales, protecting the trees from shearing

[2] Daniel, T(heodore) W. *The comparative transpiration rates of several western conifers under controlled conditions.* 1942. (Unpublished doctor's thesis on file at Univ. Calif., Berkeley.)

by the wind. Usually redwoods do not grow on hillsides squarely facing the sea (Jepson 1923).

As elevation, dryness, and slope increase, redwoods become smaller and give away to other species. In the north, redwoods clothe the eastern sides of watersheds (U. S. Forest Service 1908). In the southern part of their range, redwoods are restricted to western or northern exposures. And at the extreme southern extension they are restricted almost entirely to the bottoms of narrow canyons which cut through the steep foothills that abut the ocean. Trees near the mouths of these canyons often are exposed to onshore winds and frequently have flat tops which are dead on the windward side. This effect has been attributed to the tree's inability to replace moisture lost through desiccation by the winds (Haasis 1933).

Biotic

Redwood grows within the Transition life zone (Grinnell 1935; Merriam 1898). Appropriately, this area has been called the Redwood Transition Zone to differentiate it from the Sierran Transition at higher altitudes (Jepson 1923; Person 1937). Most redwoods are within the redwood forest cover type, but a few along the eastern edge of the range grow in the Pacific Douglas-fir type. Changes from the well-defined redwood type to another are typically sharp and distinct (Society of American Foresters 1954).

Pure stands of redwood are found only on some of the best sites, usually the moist river flats and gentle slopes below 1,000 feet. Although redwood is usually a dominant tree in mature stands throughout its range, it generally is mixed with other conifers and broad-leaved trees. Douglas-fir is the most important associate. It is well distributed throughout most of the redwood type. Other conifers are more limited in distribution within the type. Important species on the coastal side of the redwood type are grand fir (*Abies grandis* [Dougl.] Lindl.) and western hemlock (*Tsuga heterophylla* [Raf.] Sarg.) northward from northern Sonoma County, and Sitka spruce northward from the vicinity of Humboldt Bay.

Conifers occurring less commonly with redwood are:

Port-Orford-cedar (*Chamaecyparis lawsoniana* [A. Murr.] Parl)
Pacific yew (*Taxus brevifolia* Nutt.)
Western redcedar (*Thuja plicata* Donn)
California torreya (*Torreya californica* Torr.).

Some conifers associated with redwood under atypical situations are:

Gowen cypress (*Cupressus goveniana* Gord.)
Knobcone pine (*Pinus attenuata* Lemm.)
Lodgepole pine (*P. contorta* Dougl.)
Sugar pine (*P. lambertiana* Dougl.)
Bishop pine (*P. muricata* D. Don).

Of the hardwoods in the redwood type, the two most abundant and generally distributed are:

Tanoak (*Lithocarpus densiflorus* [Hook. and Arn.] Rehd.)
Pacific madrone (*Arbutus menziesii* Pursh).

Other hardwoods found in the redwood type are:

Vine maple (*Acer circinatum* Pursh)
Bigleaf maple (*Acer macrophyllum* Pursh)
Red alder (*Alnus rubra* Bong.)
Golden chinkapin (*Castanopsis chrysophylla* [Dougl.] A. DC.)
Oregon ash (*Fraxinus latifolia* Benth.)
Pacific waxmyrtle (*Myrica californica* Cham.)
Oregon white oak (*Quercus garryana* Dougl.)
Cascara sagrada (*Rhamnus purshiana* DC.)
Willows (*Salix L.* spp.)
California laurel (*Umbellularia californica* [Hook. & Arm] Nutt.),

Shrubs which are redwood associates are:

Lady bloom (*Ceanothus parryi* Trel.)
Blueblossom (*Ceanothus thyrsiflorus* Eschsch.)
Creek dogwood (*Cornus x californica* C. A. Meyer)
California hazel (*Corylus cornuta* var. *californica* [A. D C.] Sharp)
Salal (*Gaultheria shallop* Pursh)
Pacific rhododendron (*Rhododendron macrophyllum* D. Don)
Western azalea (*Rhododendron occidentale* Gray)
Poisonoak (*Rhus diversiloba* T. & *G.)*
Wood rose (*Rosa gymnocarpa* Nutt.)
Thimbleberry (*Rubus parviflorus* Nutt.)
Salmonberry (*Rubus spectabilis* Pursh)
California blackberry (*Rubus vitifolius* C. & S.)
California huckleberry (*Vaccinium ovatum* Pursh)
Red bilberry (*Vaccinium parvifolium* Sm.).

A variety of herbs, many restricted to the redwood type, are found on the redwood forest floor. They include (Jepson 1935; Person 1937):

Deerfoot vanillaleaf (*Achlys triphylla* [Sm.] DC.)
Western baneberry (*Actaea spicata* L. var. *arguta* Torr.)
Glade anemone (*Anemone deltoidea* Hook.)
Wild ginger (*Asarum caudatum* Lindl.)
Longleaf mahonia (*Berberis nervosa* Pursh)
Clintonia (*Clintonia andrewsiana* Torn)
Milkmaids (*Dentaria integrifolia var. californica* [Nutt.] Jepson)
Bleeding heart (*Dicentra formosa* [Andr.] DC.)
Fairy lantern (*Disporum smithii* [Hook.] Piper)
California alum root (*Heuchera micrantha* Dougl.)
Western water leaf (*Hydrophyllum tenuipes* Hel. var. *viride* Jepson)

- Oregon coltsfoot (*Maianthemum bifolium* DC. *kamtschaticum* [Gmel.] Jepson)
- Monkey-flower (*Mimulus dentatus* Nutt.)
- Indian lettuce (*Manila parvifolia* [Moq.] Greene) Redwood sorrel (*Oxalis oregana* Nutt.)
- Sweet coltsfoot (*Petasites palmata* [Ait.] Gray)
- White-veined shin-leaf (*Pirola pieta* Sm.)
- Saxifrage (*Saxifraga* L. spp.)
- Slinkpod (*Scoliopus bigelovii* Torr.)
- Fat Solomon (*Smilacina amplexicaulis* Nutt.)
- Slim solomon (*Smilacina sessilifolia* Nutt.)
- Fringe cups (*Tellima grandiflora* [Pursh] Dougl.)
- Sugar-scoop (*Tiarella unifoliata* Hook.)
- Star flower (*Trientalis europaea* L. var. *latifolia* Torr.)
- Coast trillium (*Trillium ovatum* Pursh)
- Inside-out flower (*Vancouveria parviflora* Greene)
- Pioneer's violet (*Viola glabella* Nutt.)
- Western heart's ease (*Viola ocellata* T. & G.)
- Evergreen violet (*Viola sempervirens* Greene).

Several shade-loving ferns are important components of the ground cover under redwood stands. Sword fern (*Polystichum munitum* Presl.) is by far the most common. Others are:

- California maidenhair (*Adiantum emarginatum* Hook.)
- Five-finger fern (*Adiantum pedatum* L.)
- California wood fern (*Aspidium rigidum* Swz. var. *argutum* Eat.)
- Common wood fern (*Aspidium spinulosum* [Mull.] Swz. var. *dilatatum* Hoffm.)
- Lady fern (*Athyrium filixfoemina* L. var. *californicum* Butters)
- Bladder fern (*Cystopteris fragilis* [L.] Bernh.)
- Gold fern (*Gymnogramme triangularis* Kaulf.)
- Deer fern (*Lomaria* [*Blechnum*] *spicant* Desv.)
- Licorice fern (*Polypodium volgare* L. var. *occidentale* Hook.)
- Chain fern *(Woodwardia radicans Sm.).*

Bracken (*Pteris* [*Pteridium*] *aquilina* L. var. *lanuginosa* [Bory] Hook.) may be abundant on openly wooded hill slopes (Jepson 1935).

One grass is mentioned as a ground cover species in redwood stands. It is California vanilla grass (*Torresia macrophylla* [Thurb.] Hitchc.).

After redwood stands are logged, some of the less tolerant or sprouting plants increase greatly in abundance at the expense of the nonsprouting or tolerant species. The greatest change in flora of cutover sites, however, is caused by the invasion of many species found rarely, if at all, in the virgin forest (Person 1937).[3]

Life History

Seeding Habits

Flowering and Fruiting

The blooming period of redwood varies between late November and early March, although flowering usually is over by the end of January (Metcalf 1924; Sargent 1922; U. S. Forest Service 1948).

Weather conditions during flowering may directly affect seed quality. If flowers open during a continuous rainy period, pollen is washed from the pollen strobili. Little pollen may reach the conelets. Dry periods during flowering permit optimum dispersal of pollen and help produce seed crops of high viability.[4]

Redwood cones, which are terminal, ovoid, and $^1/_2$-inch to $1^1/_8$-inches long, mature in the autumn following flowering (Metcalf 1924) and begin to open in early September to the latter part of December (Collingwood and Brush 1955; Geiger 1926; Green 1933). Although cones persist for several months, they open and begin to shed seed soon after ripening.

Seed Production

Redwoods generally produce abundant seed almost every year, although the seed production pattern of redwood varies by individual trees and locations (Fritz 1958; Harlow and Harrar 1950; Show 1932; U. S. Forest Service 1948). Even trees in the intermediate crown-class frequently produce seed crops (Fritz 1951b). The minimum age for good seed-bearing is 20 years, but the optimum is from 60 to 100 years (U. S. Forest Service 1948).

One study showed that seed viability increased with the age of parent trees. The maximum was reached when trees were older than 250 years; seeds produced by trees less than 20 years old generally were less than 1 percent viable; but seeds

[3] See appendix for information concerning plant species found on cutover redwood lands.

[4] Lott, Hugh Carlin. *The productivity and viability of redwood* (SEQUOIA SEMPERVIRENS) *seed.* 1923. (Unpublished master's thesis on file at Univ. Calif., Berkeley.)

from trees over 1,200 years were sterile or did not exceed 3 percent in viability[5] (Metcalf 1924).

Many exceptions to redwood's general seed production pattern have been noted. A cone, for example, was found on a tree 3 years old and 12 inches tall ([Merriam] 1927). Seedlings 7 years old (Metcalf 1924) and 9 years old, and 11-year-old trees grown from cuttings have produced cones (Hein 1934). Very young redwood sprouts also produce cones (Fritz 1929a; [Merriam] 1927). In one case 5-year-old sprouts produced seed which were 8 percent sound by cutting test and 4.5 percent viable.[6] Cones produced by sprouts less than 10 years old generally contain few seed.[7]

"Fire-columns" (see section on vegetative reproduction) produce few cones during the first 4 years following the fire which caused them. About half the fire-columns bear cones in the fifth year, however, and almost all produce cones by the seventh or eighth year.[8]

Some redwoods apparently never produce seed (Fritz 1951b). An unsubstantiated opinion suggests that cone production by redwoods is determined by permanent features of the root environment, and that no cones are produced in some areas unless induced by impairment of the root system by some kind of ground disturbance (Muelder and Hansen 1961).

Redwood cones are relatively free of pests. Some cones, however, are badly deformed by larvae of a lepidopterous insect.[9] The roundheaded borer (*Phymatodes nitidus* Lec.) is found frequently in cones (Keen 1952). And the redwood chickaree (*Sciurus douglasii mollipilosus* [Audubon & Bechman]) steals a few seeds by cutting cones.

A redwood cone has 15 to 20 scales, and each scale produces 2 to 5 seeds (U. S. Forest Service 1948). The number of seed per cone averages 60 (Metcalf 1924).

Cones number about 330 per pound (Metcalf 1924), and 100 pounds of cones yield about 11 pounds of seed (Metcalf 1924; U. S. Forest Service 1948). The number of seed per pound averages 123,000 and ranges between 59,000 and 300,000. The average seed size within redwood's natural range may increase from south to north (U. S. Forest Service 1948).

Seeds are mature when cones turn color from green to greenish yellow, or when the cone scales separate slightly (Metcalf 1924). Specific gravity of the seed does not indicate seed maturity or quality. Seeds of lower specific gravity often are more viable than seeds of higher density. Soundness in one seed lot did vary significantly with seed size. Seeds passing 12, 10, and 8 mesh screens were 2, 8, and 15 percent sound, respectively.[10]

Germinative capacity of redwood seed varies from 1 to 36 percent and averages 10 percent (U. S. Forest Service 1948). Seed viability may vary widely from tree to tree. Fritz (1951b) reported that one tree 8 feet in diameter and about 300 feet tall was heavily laden with cones, but the seeds were too poor in quality to collect; other trees, some as young as 20 years, produced seed with germinative capacities over 40 percent.

Poor average germination often is caused by the high percentage of empty seed rather than by dormancy (U. S. Forest Service 1948). Germination-cutting-test ratios varied from 65 to 95 percent and averaged 71 percent.[11] When obviously empty seed are removed, germination may be as high as 79 percent (Boe 1961). Seeds from seven sources recently were photographed by X-rays. The distribution of seeds in categories were: empty or tannin filled, 58 to 97 percent; seeds with embryos damaged by fungi, 0 to 11 percent; and sound seed, 1 to 32 percent (Hansen and Muelder 1963).

Redwood seed does not seem to store well. One seed-lot was stored successfully for 3 years, but lost its viability completely after 5 years (Schubert 1952).

Seed Dissemination

Redwood cones dry readily under conditions of low humidity and quickly release their seeds with slight shaking. But weather conditions at cone ripening usually are unfavorable for rapid drying. Therefore, seed dispersal may be spread over periods varying considerably in length, depending upon the dryness of the site. Significant factors include altitude and exposure.

[5] Lott, H. C. *Op. cit.,* footnote 4.
[6] Lott, H. C. *Op. cit.,* footnote 4.
[7] Person, Hubert L. and Hallin, William. *Possibilities in the regeneration of redwood cut-over lands.* 79 pp., illus. 1939 (Unpublished report on file at Pacific SW. Forest & Range Exp. Sta., U.S. Forest Serv., Berkeley, Calif.)
[8] Person and Hallin. *Op. cit.,* footnote 7.
[9] Lott, H. C. *Op cit.,* footnote 4.
[10] Lott, H. C. *Op cit.,* footnote 4.
[11] Lott, H. C. *Op cit.,* footnote 4.

At the other extreme, rains also may hasten seed dissemination. One observer found in many instances "that redwood seeds remain in the open cones until a drenching rain soaks the tannic crystals (in the cones) and dissolves them."[12]

Seed dissemination during the winter months seems characteristic of redwood in the northern stands. More than four-fifths of the sound seed counted in one study was shed during December and January (Boe 1961).

Redwood seeds are small and light, but lack efficient wings to slow them in falling. Therefore, redwood seeds fall at rates between 4.9 and 20.5 feet per second, averaging 8.6 feet. These rates are faster than for most other forest seed and limit seed dispersal considerably[13] (Siggins 1933).

Timbered edges of clearcut units have effective seeding distances of only 200 feet uphill and 400 feet downhill under average redwood stand conditions (Person and Hallin 1942). A clearcutting in Del Norte County received sound seeds in proportion to the number of trees in the border and the distance from them (Boe 1961). A margin of 12 trees produced 2 million seeds per acre; a margin of 20 trees produced 3 million. At the center of the clearcutting, 400 feet from timbered edges, the seed fall was only 196,000 per acre. About 8 percent of the seed falling at the timbered edges was sound, but only 4.4 percent was sound at the center. Under these conditions, areas 500 to 600 feet from timbered margins will not receive enough sound seed for prompt regeneration.

The largest clearcut units, therefore, should be nearly round or square and not much larger than 20 acres until larger experimental cuttings have been studied.

In partially cut stands in Mendocino and Humboldt Counties, the minimum number of seed trees needed to provide acceptable stocking varied from 4 per acre on north slopes, with favorable ground conditions, to 8, or more, for south exposures (Person and Hallin 1942). In Del Norte County more than 1.4 million sound seeds per acre fell under a shelterwood stand of 3 seed trees per acre, and 4.4 million seeds fell in the selection cutting where 14 seed trees to the acre were reserved (Boe 1961).

[12] Siggins, Howard William. *Dissemination by wind of seed of important conifers of California* 1926. (Unpublished master's thesis on file at Univ. of Calif., Berkeley.)

[13] Siggins, H. W. *Op. cit.,* footnote 12.

Although rodents have been accused of finding and consuming redwood seed (Fritz 1950) they probably do not alter the effectiveness of redwood seed fall. The deer mouse (*Peromyscus maniculatus rubidus* Osgood), the most abundant small mammal found on cutover lands in Del Norte County, does not seem to seek redwood seed for food[14] (Boe 1961).

Vegetative Reproduction

Redwood has the potential for propagation by cuttings (Metcalf 1924), but no large scale attempts at this kind of reproduction have been reported. In one instance, cuttings from the tops of fast growing seedlings were nonchalantly pushed into forest nursery soil; these cuttings received no special treatment, but 40 percent developed new root systems (Fritz 1929a).

The ability of redwood to sprout at any season of the year within two or three weeks after logging is an outstanding characteristic possessed by no other commercial conifer.[15] Numerous and vigorous sprouts originate close to the stumps from adventitious buds on the large lateral roots. In one area, where the average stump diameter was 35 inches, the number of sprouts averaged 72 for each stump (Metcalf 1924), but stumps often are circled by more than 100 sprouts (Jepson 1910; Jepson 1923). Each sprout soon develops its own root system and competes with its neighbors. In a remarkably short time the dominant sprouts create circles of new trees around the old stumps.

Any individual redwood may have the ability to sprout abundantly, but this power is stronger on the better forest sites and may be influenced by the tree's size and age. One study[16] showed, for example, that 100 percent of the stumps under 30 inches in diameter sprouted. Only 82 percent of the stumps 50 to 70 inches in diameter, and 52 percent of those over 110 inches in diameter sprouted. In another study (Pacific SW. Forest &

[14] Patterson, David W. *Response of animal population to logging in the redwood forest region and an investigation into the possible utilization of redwood seeds* (SEQUOIA SEMPERVIRENS) *by animals on the area.* 1960. W. M. 125 Project. (Unpublished report on file at Humboldt State College, Arcata, Calif.)

[15] Two conifers associated with redwood also sprout from stumps. Sprouting is vigorous by California torreya but weak by Pacific yew (Jepson 1910).

[16] Personal correspondence with William E. Hallin, U.S. Forest Service, February 2, 1963.

Range Expt. Sta. [1963]), 62 percent of all redwood stumps sprouted. Eighty-one percent of the stumps less than 56 inches in diameter sprouted, but only 36 percent of the stumps over 126 inches produced sprouts.

Redwood stumps in northern Humboldt County were examined in another study. Trees providing these stumps varied in age from 250 to 1,500 years. Sprout development was most vigorous around stumps of trees 500 to 700 years old, and no sprouting was observed for stumps of 15 trees which were older than 1,200 years when cut.[17]

Early estimates of stocking from sprouts varied from 20 to 35 percent of full stocking (Fisher, van Schrenk and Hopkins 1903; Mason 1922). Later, these estimates were recognized as high (Metcalf 1924; Show 1932) because they apply only when the best quality pure redwood stands, found on alluvial benches, are logged. Redwood sprouts on typical cutover redwood land in Mendocino and Humboldt Counties stocked 8 percent of the milacres examined (Person and Hallin 1942).

Sprouting by redwood is not limited to root crowns. Sprouts often grow from the sides or tops of stumps. These are undesirable because, first, they must rely on conductive tissues of the parent stump, second, they are mechanically weak, and third, they are not as vigorous as root-crown sprouts. Root sprouts also are mentioned in published reports,[18] but foresters familiar with redwoods often question their importance, and, in some cases, their existence. A careful study showed that 76 percent of sprouting stumps produced the sprouts from the root crown, and 9 percent had root sprouts (Pacific SW. Forest & Range Exp. Sta. [1963]).

Redwood also can sprout along almost the entire length of its trunk. If the crown of a tree is destroyed by fire, mechanically damaged, or exposed to stronger light, numerous buds along the trunk are stimulated and produce new foliage. Trees in this condition are called "fire columns" because they have a typical appearance. Most of the trunk will be covered by feathery foliage 2 or 3 feet thick (Jepson 1910). Eventually, normal crowns develop again.

A redwood seedling begins to develop a burl around its stem slightly under the soil surface when about 6 months old. This burl soon produces many dormant buds, some of which will sprout if the seedling's top is injured (Cooper 1965). Even where fire has burned away the tops of trees in plantations less than 2 years old; most of the basal burls are uninjured and the seedlings sprout again (Mason 1924). Detailed examinations on separate burns showed that almost 90 percent of the redwood seedlings top-killed by fires sprouted (Person 1937).

Seedling Development

Establishment

Redwood seed generally is ready to germinate soon after it falls to the ground if seedbeds are moist and the weather is warm enough. As a rule, seed do not require pretreatment for germination. Occasionally, however, germination has been improved by stratification, indicating slight and variable seed dormancy (U. S. Forest Service 1948).

The period of germinative energy averages 35 days, but may vary by as much as 20 days between individual seedlots receiving the same treatment.[19] Under laboratory conditions one seed lot reached the peak of germination in I4 days, and only a few seed germinated after 23 days (Boe 1961).

Mineral soil is the best seedbed,[20] but seed will germinate readily in duff, on logs, in debris, or under other vegetation, and in either shade or full sunlight, provided that adequate soil moisture is available (Fritz 1950; Fritz 1958). Redwood seed germination is epigeous. Cotyledons generally number two, rarely three or four (Butts and Buchholz 1940; Hill and Fraine 1908).

New redwood seedlings require a greater supply of soil moisture for survival than that needed by seedlings of most of its associated trees. Therefore, the incidence of late spring and early fall rains can be critical survival factors (Fritz 1958).

Apparently, redwoods have no root hairs. Consequently, redwood roots do not seem to function efficiently in extracting soil moisture. This fact may limit natural distribution to sites where favorable water relations result from high rainfall, humid air, moist soil, or low summer temperatures, or from various combinations of these conditions (Cannon 1926).

[17] Personal correspondence with Robert F. Powers, Humboldt State College, September 14, 1965.

[18] Mason 1922; Metcalf 1924; U. S. Forest Service 1908; Van Dersal 1938.

[19] Lott, H. C. *Op. cit.,* footnote 4.

[20] Fritz 1951b; Metcalf 1924; Pacific SW. Forest & Range Exp. Sta. (1963): Person and Hallin 1942; U. S. Forest Service 1948.

Redwood seems capable of extremely high transpiration rates. Therefore, long periods of relatively low humidity, with resulting evaporational stress, could prevent redwood from maintaining its internal vapor pressure and desiccate the foliage.[21]

Seedlings usually grow best on exposed mineral soil because there they need not compete with other vegetation (Fritz 1951b; Person and Hallin 1942). A broken soil surface that will help retain moisture during the first two dry seasons is another desirable seedbed condition (Fritz 1958). Partial shade during the first few months after germination also is beneficial (Metcalf 1924; Person and Hallin 1942).

Redwood seedlings on fully exposed soil can withstand considerable surface heat if their roots have reached an abundant permanent moisture supply. Otherwise, they die before soil surface temperatures reach 140° F. (Fritz 1958).

Light slash sometimes may be desirable (Fritz 1951b) because it provides shade, but areas where slash burning was classified as medium and heavy had 5 to 10 times as much reproduction as unburned or lightly burned cutover areas (Person and Hallin 1942).

A dense vegetative cover becomes reestablished rapidly on redwood cutover lands. Therefore, the first two years following logging and slash disposal are the most favorable for natural regeneration (Person and Hallin 1942). Redwood seedlings withstand the competition of fireweeds (*Erechtites* spp. and *Epilobium angustifolium*) which often solidly cover cutover lands (Fritz 1950). These tall herbs and others are erect but not bushy. They may serve as nurse plants by giving maximum protection from sun and wind with minimum competition for soil moisture.

Far better stocking of smaller seedlings is associated with tall herbs than with low herbs, ferns, and shrubs which become more abundant with time. Only a negligible amount of stocking is added by new seedlings after the first four years. The poorest stocking definitely is associated with grass.[22]

Seedling mortality is heaviest the first year and is caused by a variety of factors. Small redwood seedlings may die because moisture is deficient. This condition is most common on south slopes where natural stocking has been 24 percent less than on other aspects.[23] Frost heaving occurs infrequently, and rarely on other than north slopes (Fritz 1950).

Slugs, snails, birds, and rodents have been suspected of destroying redwood seedlings (Fritz 1950). But although slime trails of the large Columbian slug (*Ariolmax columbianus* [Gould]) may sometimes smother tiny redwood seedlings, neither this slug, nor the large shelled snail (*Monadenia fidelis* [Gray]), or birds, have been observed eating redwood seedlings. If any small mammals damage redwood seedlings, the meadowmice (*Microtus* spp. Schrank) are the most likely culprits.[24]

Known destructive agents include brush rabbits (*Sylvilagus bachmani ubericolor* [Miller]), which eat the tops of young redwood seedlings, and Columbian black-tailed deer (*Odocoileus hemionus columbianus* [Richardson]) and cattle, which browse seedlings, particularly after they are about 1 foot high. And tall herbs, which may be desirable when green and standing, sometimes kill small seedlings by falling over to form a thick smothering mat (Fritz 1950).

Established redwood seedlings are scarce in undisturbed forests. Their absence has been attributed to root rot fungi in the A soil horizons (Muelder and Hansen 1961; Florence 1965).

Early Growth

In its early stages redwood sometimes grows rapidly in both height and diameter (Green 1933). Height growth of 18 inches in the first season is not unusual for seedlings (Fritz 1929a), but slower growth during the first 4 or 5 years is more common. Where seedlings numbered 900 to 2,100 per acre, annual height growth ranged between 2.5 and 14 inches (Cooper 1965). In one case planted redwoods were only 7, 12, and 35 inches tall at 1, 4, and 6 years after logging, respectively (Person 1937). Another study showed virtually all natural redwood seedlings to be less than 1 foot tall when 5 years old. In this instance grand fir and Douglas-fir were significantly taller at the same age.[25] Height growth of redwood usually accelerates when seedlings are 4 to 6 years old. Leaders of

[21] Daniel, T. W. *Op. cit.,* footnote 2.

[22] Person and Hallin. *Op. cit.,* footnote 7.

[23] Person and Hallin. *Op. cit.,* footnote 7.

[24] Personal correspondence with Robert R. Talmadge, Willow Creek, California, March 7, 1964.

[25] Personal correspondence with William E. Hallin, U. S. Forest Service, October 26, 1965.

trees 4 to 10 years old frequently grow 2 to 6½ feet in a year (Harlow and Harrar 1950; Jepson 1910), and one tree grew 7.3 feet in a year (Cooper 1965).

Sprouts are commonly 24 to 36 inches high at the end of the first year, but often are taller (Fritz 1929a). They may be over 6 feet tall in a year (Fritz 1945). In one case a fire killed all sprouts around a stump. About 300 new sprouts appeared at once, and at the end of one growing season many reached 7 feet (Fritz 1929a). Sprouts grow more rapidly than seedlings because they obtain great nourishment from the parent trees' root systems. The initial impetus lasts many years.[26]

Root growth by seedlings is best in loose soil. A 1-year-old tree may have roots only 3 inches deep in compacted soils, but more than 12 inches deep and abundantly branched in loosened soils (Fritz 1950).

A diurnal temperature variation is not required for maximum growth of redwood seedlings (Hellmers and Sundahl 1959). But with diurnal temperature variations, redwood seedlings grew tallest when the day temperature was 66° F. and the night temperature was 59° F. Increased temperatures, either day or night, decreased growth, and a decrease in night temperature from 59° F. to 52° F. restricted growth markedly (Hellmers 1964). Roots developed best in the laboratory when the soil temperature was 64° F. compared to temperatures of 46° F. and 82° F. (Hellmers 1961).

Juvenile growth of redwood is best in full sunlight, but redwood seedlings can endure heavy shade, although growth may be slow (Fritz 1950). Redwood has a remarkably efficient system for photosynthesis. Seedlings of this species grew vigorously in much weaker light than 12 other tree species tested by Bates and Roeser (1928). For example, redwoods increased their size 8.8 times in 10 percent of full sunlight in a 9-month period. This was more than twice the growth of any other species. For appreciable growth Engelmann spruce (*Picea engelmannii* Parry) and Douglas-fir require as much light as redwood, and pines, as a group, require three to four times as much.

[26] Barnes, John Scott. *Redwood growth studies: I. The relative volume production of sprouts and seedlings in second growth. II. The height growth of young redwood in mixture. III. A site classification for virgin stands.* 1924. (Unpublished master's thesis on file at Univ. Calif., Berkeley.)

Seasonal Growth

Information on seasonal growth of redwood is almost nonexistent. Limited measurements of radial growth of redwood in Mendocino County at points 4, 9, and 20 miles from the coast showed no marked locational growth pattern differences. Radial growth began after mid-March, increased to a maximum in late May, and then declined at a fairly uniform rate to a minimum at the end of September. Growth was negligible from October 1 to March 15 (Bawcom, Hubbell, and Burns 1961).

One report (Cooper 1965) indicates that redwoods 6 months to 40 years old began height growth in Del Norte and Humboldt Counties between January 1 and 18, even when night temperatures dropped below the frost point. Height growth generally ended by mid-July but sometimes continued another 2 months.

Sapling Stage to Maturity

Growth and Yield

Besides growing in a special habitat, the redwood itself is unique—it is long-lived, grows taller than any other tree in the world, and is exceeded in bulk only by the giant sequoia (*Sequoia gigantea* [Lindl.] Decne.) of the Sierra Nevada.

In age, redwoods are mature at 400 or 500 years (Jepson 1910; Jepson 1923; U. S. Forest Service 1908). The oldest tree so far found by actual growth ring counts is just under 2,200 years (Fritz 1957).

Virgin redwood forests sometimes are incorrectly called even-aged and over-mature, when, in fact, there is no other forest in the world that can match many redwood stands in range of ages and mixture of vigorously growing and decadent trees. For example, when ages of trees on a 30-acre tract typical of Humboldt County were determined, all ages were represented. The oldest was 1,380 years (at stump height), and the runner-up was 1,246. Not counting more than 1,000 trees under 12 inches in diameter, the trees were distributed by broad age classes as follows (Fritz 1929b):

Age, years:	*Number*	*Percent*
0-200	696	55
201-400	197	16
401-600	183	15
601-800	105	8
801-1,000	65	5
Over 1,000	17	1
	1,263	100

Redwood probably is best known for its great size although the average redwood is smaller than many persons realize. Trees larger than 12 inches in diameter, measured on the 30-acre tract mentioned above and classed by diameters, fell approximately into these divisions: 12 to 30 inches, 50 percent; 31 to 60 inches, 32 percent; 61 inches and larger, 18 percent. Redwoods 12 to 16 feet in diameter, found scattered over the entire range, are considered large. A few trees 20 feet in diameter, or slightly larger, at a point 5 feet above the ground have been found, but these are rare (Fritz 1929a; Fritz 1957).

Redwoods taller than 200 feet are common, and many trees growing on the alluvial benches, where the soil is deep and moist, are taller than 300 feet. The three tallest trees of record grow in Redwood Creek Grove, about 7 miles southeast of Orick, Humboldt County. They measure 367.8, 367.4, and 364.3 feet, respectively (Zahl 1964).

The largest diameters and heights are not necessarily found in the same trees. The "Founders' Tree" is 352.6 feet tall, but only 12 feet 7 inches in diameter at breast height. The greatest volume of wood in any standing tree may be contained by the "Giant" at Rockefeller Grove on Bull Creek Flat. This tree is 356.5 feet tall and 16.5 feet in diameter.

One tree in the Maple Creek drainage, Humboldt County, was over 20 feet in diameter, 5 feet above the ground, and 308 feet tall. It had such slight taper that it was still more than 12 feet in diameter 230 feet above the ground. Its merchantable volume scaled 361,366 board feet by the Spaulding log rule, enough to build 22 average houses.[27] Another tree is supposed to have tallied 480,000 board feet from the saw,[28] but this record is unconfirmed.

Large trees and dense stocking combine to produce high yields. More than 81 percent of the commercial redwood forest land is classified as highly productive, and only 2 percent is poor for growing trees. Individual acres yielding more than 100,000 board feet of sawtimber are common, even on slopes (Collingwood and Brush 1955; Fritz 1929a). Recent cuttings in Del Norte County (Boe [1960]; Boe 1963), on units of 13 acres and larger, produced gross volumes ranging from 95,-000 to 280,000 board feet (Scribner) per acre. Defect in logs hauled was about 12 percent, and about 40,000 board feet of cull logs and broken wood were left on the ground. The number of merchantable trees varied from 29 to 46 per acre, and tree sizes were from 14 to 198 inches in diameter.

Flats along rivers have yielded more than 1,-000,000 board feet per acre in scaled logs.[29] One acre is reported to have contained 2,500,000 board feet, yielding 1,500,000 board feet of cut lumber (Anon. 1902; Jepson 1910; Peattie 1953). This report is not documented.

Performance of young-growth redwood is, in its own way, often as spectacular as the dimensions and yields of old growth. Dominant young-growth trees on good sites are 100 to 150 feet tall at 50 years, and 165 to 220 feet at 100 years (Boe [1960]). Height growth is most rapid up to the 35th year (Lindquist and Palley 1961).

Diameter growth of individual young trees can be rapid or very slow. In dense stands where competition for light and soil moisture is severe, annual radial increment is commonly as small as one-thirtieth-inch. Occasionally there are 100 rings per inch. At the other extreme, under ideal conditions, radial growth can be as great as 1 inch a year. One redwood growing with little competition reached 84 inches in diameter in 108 years (Fritz 1957).

The yield of young-growth redwoods stands at 100 years is expected to range from 56,000 board feet per acre on low sites to 358,000 board feet on high sites. Much of the acreage now under management will grow 2,400 board feet per acre per year (Lindquist and Palley 1963).

Hallin (1934) reported an exceptional case, in which the annual growth of a 260-year-old stand had averaged 2,987 board feet per acre. Growth had been much faster during the first 150 years, however; ring counts showed it probably was between 3,500 and 4,000 board feet per acre. At 260 years the dominant trees were 37 to 80 inches in diameter, averaging 50.6 inches, and their heights averaged 256 feet. The largest tree was 80 inches in diameter at breast height, and 270 feet tall.

Natural pruning in young redwood stands often is not good. Although live crowns may be limited to no more than the upper third of the trunk, dead limbs are persistent. Stubs, although decayed, may remain over 50 years. In old growth, some branch

[27] Fritz 1929a; Fritz 1930; Fritz 1957; Tiemann 1935.

[28] Anon. 1902; Harlow and Harrar 1950; Jepson 1910; Peattie 1953; Preston 1948.

[29] Browne 1914; Fritz 1929a; Fritz 1930; Fritz 1957; U. S. Forest Service 1908.

stubs have been found which affected the quality of the timber produced over a 200-year period (Fritz 1951b; Fritz 1958). But trees in the intermediate crown class often prune well naturally (Fritz 1958). Some trees in a heavily stocked stand had clean trunks for 75 to 100 feet at 85 years (Fritz 1945).

Reaction to Competition

When 55 foresters ranked redwood in a scale of five broad tolerance classes, all of them placed it in either the highest or second highest class—40 percent called redwood "very tolerant," and 60 percent judged it "tolerant" (Baker 1949).

Redwood stands are dense. The average well stocked acre supports nearly 1,000 stems at 20 years, including 500 dominant and codominant trees. At 60 years redwood has a basal area of 486 square feet on the best sites (Bruce 1923). Close stocking is desirable because the relatively high tolerance to shade permits an acre to support a large number of dominant and codominant trees.[30]

Redwoods can endure suppression almost indefinitely. Small suppressed trees often grow so slowly that 40 growth rings are required to produce an inch of radius; and a 10-inch tree might be well over 100 years old (Fritz 1938).

Small trees may be suppressed for over 400 years but still maintain a remarkable capacity to accelerate growth rates when released, if they are not injured seriously during logging or slash-burning operations (Fritz 1940; Merrill 1953b). A 12-inch tree, 160 years old, about 100 feet tall and over-topped by a 300-foot-high stand containing about 165,000 board feet per acre, increased its annual growth rate from less than 1 percent to almost 20 percent for the first 10 years after the overstory was removed (Fritz 1951b). Other small trees, with only one-fifteenth-inch growth rings, increased annual radial growth to one-third inch after partial cutting (Fritz 1929a).

Large trees also are capable of accelerating growth when released from competition with their neighbors. A 1,000-year-old tree, for example, increased its radial growth from 30 rings to 6 rings per inch when it was only partially freed from competition by cutting on a highway right-of-way (Fritz 1951b).

The redwood forest is a climax type. When growing with other species redwood is always a dominant tree.

[30] Person and Hallin. *Op cit.,* footnote 7.

Principal Enemies

Fire is redwood's worst enemy throughout life. Young stands can be destroyed outright by a single ground fire (U. S. Forest Service 1908). Fires are especially damaging to trees less than 20 years old because the thin bark of young trees does not protect them. Also, more flammable litter lies on the ground, and the microclimate is drier than under old-growth forests (Fritz 1932).

Old-growth redwood stands show evidence of three or more severe fires each century (Fritz 1957). In many cases fires may only reduce the thickness of the protective bark—ground fires often cause the basal bark to be thinner on one side of the tree, and thinner than bark higher up the tree (Kimmey and Hornibrook 1952). In other cases fires injure the cambium and wood. Rots enter through these basal fire wounds, destroy heartwood, and prepare better fuel for the next fire. The combination of recurring fires and advancing decay produce large basal cavities called "goose pens" (Fritz 1932). In extreme cases mature trees may be so weakened mechanically that they fall (Fritz and Bonar 1931).

Redwood has no tree killing diseases, but heart rots cause extensive cull in extreme cases rot may extend from the center of the tree to within 8 inches of the bark, and for the full length of the bole (Fritz 1957).

Two principal fungi attack redwood heartwood. They enter trees through fire scars, logging wounds, broken tops, or other wounds which expose the heartwood. Most common heart rot in the southern part of redwood's range is a brown cubical rot caused by *Poria sequoiae* Bonar; a white ring rot caused by *Poria albipellucida* Baxter is most important farther north (Kimmey and Hornibrook 1952). Other decay fungi have been identified in redwood, but they have caused negligible volume losses;[31] (Kimmey and Lightle 1955).

Only one disease which is a potential killer is known. This is a twig and branch canker (*Coryneum* sp.) which has been observed on sprouts and plantation trees of seedling and sapling size. This canker, which girdles small stems and branches, could become damaging in plantations.[32]

Several insects are found on redwood, but none causes significant damage (Essig 1926; Keen

[31] Forest Disease Research, Host Index File. U. S. Forest Serv. Pacific SW. Forest & Range Exp. Sta., Berkeley, Calif.

[32] Personal correspondence with Willis W. Wagener, U. S. Forest Service, Feb. 19, 1963.

1952). These include the redwood scale (*Cryptaspidiotus shastae* Cole.) which sometimes becomes abundant, the redwood mealy-bug (*Pseudococcus sequoiae* Cole.), and the cypress mealy-bug (*Pseudococcus ryani* Coz.). A flatheaded twig borer and girdler, *Anthaxia aeneogaster* Cast., mines the bark and outer wood, and may kill small trees or branches. The redwood barkbeetle (*Phloesinus sequoiae* Hopk.) mines the inner bark of injured, dying, or dead trees. Larvae of the twig borer (*Phloesinus cristatus* Lec.) work under the bark of twigs and limbs of declining or dead redwoods. And sequoia pitch moths (*Vespamima sequoiae* Hy. Edw.) mine the cambium of redwood branches and boles.

The dusky-footed wood rat (*Neotoma fuscipes fuscipes* Baird) is one of the most harmful factors limiting the survival of planted trees on old cutover land. Fortunately, rodent damage usually is not severe on newly logged land (Person 1937). Wood rats also attack sprouts occasionally, but usually cause little damage to these larger trees (Fritz 1951a).

The California gray squirrel (*Sciurus griseus griseus* Ord.) sometimes causes considerable damage in local areas by stripping bark from large saplings or from the thin-barked upper crowns of larger young trees (Fritz 1950). When sprouts are damaged this way, they may lose all their foliage on the side facing the mother stump. Discontinuous growth rings are a common result of this kind of loss. Although normal growth increments are produced on the side of the stem facing away from the stump, the inner side may remain dormant for a number of years (Fritz and Averell 1924).

Bark stripping by the American black bear (*Euarctos americanus americanus* [Pallas]) has become serious in some parts of the redwood region (Fritz 1951a). Bears rip wide strips of bark from the tree, frequently from the top to the ground, from April to August. The bears then scrape the juicy sapwood with their teeth. Many trees are girdled (Merrill 1953a). Trees 10 to 30 years old and 6 to 10 inches in diameter are damaged most (Glover and Hansen 1952).

Young redwoods are easily injured by frost, especially in the spring. Sometimes they are killed (Dallimore 1931; Fritz 1958).

Redwood also is easily damaged by strong winds. When exposed to prevailing winds, redwoods generally have deformed leaders and height growth is slow. Associated species often provide enough protection so that redwoods grow normally in mixed stands on sites where it would be deformed if growing alone (Metcalf 1924).

Redwoods have no tap roots, but lateral roots are large and wide-spreading (Fritz 1929a; U. S. Forest Service 1908). Small trees have better than average windfirmness (Fritz 1958), and large redwoods are windfirm under most conditions (McCollum 1957; U. S. Forest Service 1908).

From a study in Del Norte County, Boe ([1960]; 1966) concluded that a combination of wet soil and strong winds is necessary for significant windfall damage, and consequently windfall is caused by only few of the many winter storms. Uprooting accounted for 80 percent of the redwood windfall in this study. Other destroyed trees were broken, but rot was not an important factor. Winds from the southeast-southwest sector caused the damage. In partial cuttings the smaller codominant and intermediate trees were most frequently blown down. Windfall was least in shelterwood cuttings where vigorous codominant trees were chosen for the reserve stand. In clearcuttings, the leeward margins were most damaged by wind.

Special Features

A prominent special feature of the redwood is its production of burls from which beautifully figured table tops, veneers, bowls, and other turned products are cut. These burls are found on any part of the trunk and in sizes varying from an inch to many feet in diameter. Even young seedlings produce burls that encircle the stems just below the ground line. If these seedlings are killed back by frost, drought, or fire, they generally sprout from the small burls (Cannon 1926; Fritz 1929a).

In old growth, burls 5 to 6 feet in diameter are common, and some, even larger, completely encircle a tree. The longest recorded (Fritz 1928) was 60 feet, and the largest was a pyramidal basal burl measuring 75 feet in circumference at its base and containing 30,000 board feet of beautifully figured wood.

The cause of burls is unknown. They form from closely-spaced, persisting dormant buds which produce an intricate grain as growth rings are added each year. Burls on trees seldom produce shoots, but profuse sprouts grow from young burls after they are removed and placed with their cut surfaces in shallow water (Fritz 1928).

Another feature of redwood is its extremely tough and fibrous bark. The tree has been classed as thick-barked. Bark sometimes is as much as a foot thick, but usually is much less (Isenberg 1943). This bark must be removed before logs reach the head saws so that sawing uniform lumber will be possible (Fritz 1940). The bark contains no traces of oil or resin (Anon. 1902). It has been shredded and used for upholstering (Kellogg 1882) and for insulation. Both bark and wood contain tannin which has been used widely to control the viscosity of mud for oil-well drilling and to produce leather (Carr 1956).

On the alluvial flats where redwoods reach their maximum development, soils have been built up by deposits of sediment from successive floods. In one area the ground level had been raised 11 feet in 700 years (Fritz [1934]). In another, repeated flooding in the last 1,000 years has deposited nearly 30 feet of silt and gravel around the bases of many large redwood trees (Stone and Vasey 1962). Individual deposits have been as deep as 30 inches. Redwoods adapt themselves to the new ground levels by originating new and higher root systems (Fritz [1934]). That they respond to each deposit by stimulating diameter growth has been suggested (Univ. Calif. School Forestry 1960), but not proved.

Races and Hybrids

Foresters do not recognize races of redwoods, but the following varieties have been described (Dallimore and Jackson 1948) :

- var. *adpressa* Carriere
  - Tips of shoots creamy white. Awl-like leaves.
- var. *glauca* R. Smith
  - Leaves 1/4 -inch long and glaucous.
- var. *gracilis* Hort.
  - Branchlets slender.
- var. *pendula* Rovelli
  - Branches pendulus.
- var. *taxifolia* Hort.
  - Leaves broader than in the type.

A Russian reports hybridization of redwood with giant sequoia (*Sequoia gigantea* [Lindl.] Decne.), baldcypress (*Taxodium distichum* [L.] Rich.), and Japanese cryptomeria (*Cryptomeria japonica* D. Don) (Yablokov 1960).

Stebbins (1948) proposed an interesting hypothesis concerning the origin of redwood (2n 66 chromosomes): that redwood originated as an allopolyploid from hybrids between an early Tertiary or Mesozoic species of *Metasequoia* S. Miki. and some probably extinct Taxodiaceous plant like the modern giant sequoia, taiwania (*Taiwania cryptomeriodes* Hyata), or Tasmanian cedars (*Athrotaxis* Don spp.) .

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Appendix

Table 1.--*Plant species, other than trees, found on cutover redwood lands in Humboldt and Mendocino Counties, California.* [1, 2]

TALL WOODY SHRUBS

Vegetation group and species (species above lines are listed in order of dominance)	Order of dominance within same group in virgin stands	↓
Ceanothus thyrsiflorus Eschsch.	blueblossom	7
Vaccinium ovatum Pursh	California huckleberry	2
Rhododendron macrophyllum D. Don	Pacific rhododendron	1
Salix L. spp .[3]	willows	10
Arctostaphylos columbiana Piper	hairy manzanita	14
Vaccinium parvifolium Sm.	red bilberry	3
Myrica californica Cham. [3]	Pacific bayberry or waxmyrtle	4
Corylus rostrata var. *californica* A. DC.	California hazel	5
Baccharis pilularis DC.	coyote brush	[4/]E
Rhamnus purshiana DC.	cascara sagrada	8
Acer circinatum Pursh[3]	vine maple	
Ceanothus velutinus Dougl.	snowbrush	
Holodiscus discolor (Pursh) Maxim.	cream bush	
Ribes L. spp.	gooseberry and currant	
Sambucus glauca Nutt.	blue elderberry	
Sambucus callicarpa Greene	elderberry	
VINELIKE SHRUBS AND FERNS		
Gaultheria shallon Pursh	salal	1
Pteris (Pteridium) aquilina L. var. *lanuginosa* (Bory) Hook.	bracken	E
Polystichum munitum Presl.	sword fern	2
Rubus vitifolius C. & S.	California blackberry	5
Rubus parviflorus Nutt.	thimbleberry	3
Berberis nervosa Pursh	longleaf mahonia	6
Rhus diversiloba T. & G.	poisonoak	4
Rubus leucodermis Dougl.	western raspberry	9
Lonicera hispidula Dougl. var. *californica* Jepson	California honeysuckle	
Rosa *californica C.* & *S.*	California wild rose	
Rubus spectabilis Pursh	salmonberry	
Woodwardia radicans Sm.	chain fern	
TALL HERBS		
Erechtites prenanthoides DC.	Australian fireweed	E
Epilobium angustifolium L.	fireweed	E
Anaphalis margaritacea (L.) B. & H.	pearly everlasting	E
Erechtites arguta DC.	New Zealand fireweed	E
Iris douglasiana Herbert	mountain iris	1
Iris macrosiphon Torr.	ground iris	2
Lotus stipularis (Benth.) Greene var. *subglaber* Ottley	bird's-foot trefoil	11
Baccharis douglasii DC.	Douglas baccharis	E
Gnaphalium *decurrens* Ives var. *californicum* Gray	California everlasting	E
Cirsium arvense Scop.	Canada thistle	E

Footnoted at end of table.

Table 1.--*Plant species, other than trees, found on cutover redwood lands in Humboldt and Mendocino Counties, California* [1, 2] (continued)

TALL HERBS, continued

Vegetation group and species (species above lines are listed in order of dominance)	Order of dominance within same group in virgin stands	↓
Sonchus asper L. and *Sonchus oleraceus* L.	prickly sow-thistle and common sow-thistle	E
Cirsium edule Nutt.	Indian thistle	E
Epilobium paniculatum T. & G.	paniculate fireweed	10
Achillea millefolium L. var. *lanulosa* Piper	common yarrow	
Adenocaulon bicolor Hook.	adenocaulon	
Aquilegia truncata F. & M.	columbine	
Chrysanthemum leucanthemum L.	ox-eye daisy	
Epilobium watsonii Barb. var. *franciscanum* (Barb.) Jeps.	fireweed	
	horseweed	
Gnaphalium ramosissimum Nutt.	pink everlasting	
Madia madioides (Nutt.) Greene	woodland madia	
Madia sativa Molina	Chile tarweed	
Parentucellia viscosa (L.) Caruel	parentucellia	
Sidalcea malachroides Gray	checker	
Stachys chamissonis Benth.	hedge nettle	
Tellima grandiflora (Pursh) Dougl.	fringe cups	
LOW HERBS		
Whipplea modesta Torr.	western whipplea	11
Hypochoeris radicata L.	hairy cat's ear	E
Oxalis oregana Nutt.	redwood sorrel	1
Trientalis europaea L. var. *latifolia* Torr.	star flower	15
Crepis capillaris (L.) Wallr.	smooth hawksbeard	E
Viola sarmentosa Dougl.	wood violet	7
Medicago lupulina L.	nonesuch	E
Gnaphalium purpureum L.	purple cudweed	E
Medicago hispida Gaertn.	bur clover	E
Plantago lanceolata L.	ribwort	E
Asarum caudatum Lindl.	wild ginger	
Clintonia andrewsiana Torr.	clintonia	
Dicentra formosa (Andr.) DC.	bleeding heart	
Echinocystis oregana Cogn.	hill man-root	
Erodium moschatum L'Her.	white-stem filaree	
Galium L. spp.	bedstraw	
Hypochoeris glabra L.	smooth cat's ear	
Lotus L. spp.	bird's-foot trefoil	
Montia perfoliata (Donn) Howell	miner's lettuce	
Montia sibirica (L.) Howell	Indian lettuce	
Myosotis sylvatica Hoffm.	forgetmenot	
Polygala californica Nutt.	milkwort	
Rumex acetosella L.	sheep sorrel	
Smilacina amplexicaulis Nutt.	fat Solomon	
Smilacina sessilifolia Nutt.	slim Solomon	

Footnoted at end of table.

Table 1.--*Plant species, other than trees, found on cutover redwood lands in Humboldt and Mendocino Counties, California* [1], [2] (continued)

LOW HERBS, continued

Vegetation group and species (species above lines are listed in order of dominance)	Order of dominance within same group in virgin stands ↓	
Trifolium pratense L.	red clover	
Trillium ovatum Pursh	coast trillium	
Vancouveria hexandra (Hook.) Morr. & Dec.	vancouveria	
Vancouveria parviflora Greene	inside-out flower	
ANNUAL GRASSES		
Lolium temulentum L.	darnel	E
Aira caryophyllea L.	silver hairgrass	E
Festuca megalura Nutt.	foxtail fescue	E
Bromus mollis L.	soft chess	E
Festuca rubra L.	red fescue	E
Bromus rigidus Roth.	ripgut grass	E
Polypogon monspeliensis (L.) Desf.	rabbitfoot grass	E
PERENNIAL GRASSES		
Holcus lanatus L.	velvet grass	E
Dactylis glomerata L.	orchard grass	E
Deschampsia elongata (Hook.) Benth.	slender hairgrass	E
Hierochloe occidentalis Buckl.	California sweetgrass	1
Festuca occidentalis Hook.	western fescue	E
Festuca L. spp.	fescues	E
Bromus vulgaris (Hook.) Shear	brome	E
Melica L. spp.	melicgrass	E
SEMI-AQUATICS		
	mosses	
Equisetum L. spp.	horsetails	
Juncus L. spp.	rushes	
Carex L. spp.	sedges	
Luzula DC. spp.	woodrushes	

[1] Person, Hubert L., and Hallin, William. Possibilities in the regeneration of redwood cut-over lands. 1939. (Unpublished report on file at Pacific SW. Forest & Range Exp. Sta., U.S. Forest Service, Berkeley, Calif.)
[2] Basis: 7,082 milacre quadrats surveyed in 1932.
[3] Trees listed as shrubs because their environmental effect is shrublike.
[4] Species marked E are found only on cutover areas, not in virgin stands. They are either exotics or invaders from adjacent types.

Table 2.--*Species important in virgin redwood stands but not common on cutover lands in Humboldt and Mendocino Counties, California.* [1, 2]

SHRUBS	
Cornus nuttallii Audubon	Pacific dogwood
Physocarpus capitatus (Pursh) Kuntze	ninebark
Sambucus callicarpa Greene	elderberry
Symphoricarpos albus (L.) Blake	snow berry
FERNS	
Adiantum pedatum L.	five-finger fern
Lomaria (Blechnum) spicant Desv.	deer fern
TALL HERBS	
Actaea spicata L. var. *arguta* Torr.	baneberry
Lysichiton kamtschatcense (L.) Schott	skunk cabbage
Petasites palmata (Ait.) Gray	sweet coltsfoot
Phacelia bolanderi Gray	phacelia
LOW HERBS	
Achlys triphylla (Sm.) DC.	deerfoot vanillaleaf
Disporum hookeri (Torr.) Britt.	fairy bells
Disporum smithii (Hook.) Piper	fairy lantern
Lilium L. spp.	lilies
Maianthemum bifolium DC. *kamtschaticum* (Gmel.) Jepson	Oregon coltsfoot monkey-flower
Mimulus dentatus Nutt.	slinkpod
Scoliopus bigelovii Torr.	liver-berry
Streptopus amplexifolius (L.) DC.	

[1] Person, Hubert L., and Hallin, William. Possibilities in the regeneration of redwood cut-over lands. 1939. (Unpublished report on file at Pacific SW. Forest & Range Exp. Sta., U.S. Forest Serv., Berkeley, Calif.)
[2] Basis: 7,082 milacre quadrats surveyed in 1932.