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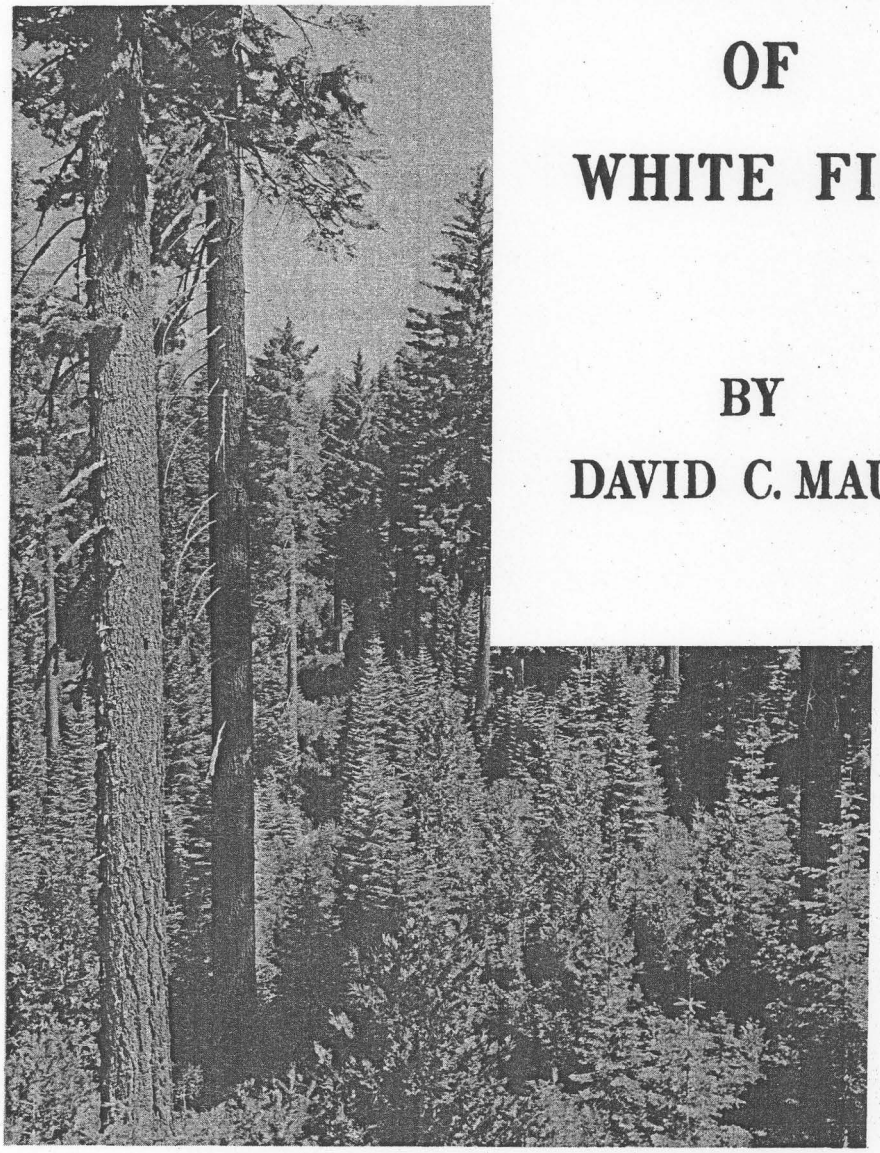
SILVICAL CHARACTERISTICS OF WHITE FIR



BY
DAVID C. MAUL

CALIFORNIA
FOREST AND RANGE
EXPERIMENT STATION
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SILVICAL CHARACTERISTICS OF WHITE FIR

By David C. Maul, Forester,
Division of Forest Management Research

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By David C. Maul 1/

RANGE

White fir (Abies concolor Gord. and Glend.) Lindl.) is an economically important native tree in western United States and parts of Mexico. In the United States it is widely distributed in the Rocky Mountain and Pacific Coast regions, extending from New Mexico and Wyoming, westward to Oregon and California (19, 21) (Fig. 1). It attains best development in California and southwestern Oregon.

HABITAT CONDITIONS

CLIMATIC

White fir is found primarily in the Transition Life Zone but also in the Canadian Life Zone. In general, white fir occurs in the higher mountain areas characterized by moderately humid to humid climate, with long winters and moderate to heavy snow deposits. Where white fir occurs in California, Oregon, Idaho, and the Great Basin country, the summers tend to be dry. In Colorado, Utah, and the Central Rockies, the portion of the annual precipitation falling as rain is fairly evenly distributed over the summer period. In Arizona and New Mexico the spring season is drier than the summer period (34).

White fir grows best in cool, moist situations (32). The lower limit of precipitation for the species is about 20 inches per year and 20 to 35 inches is common over much of the drier parts of its range. In some of the higher mountain areas and parts of the north coastal range of California precipitation on white fir sites ranges between 35 and 75 inches. The best stands of white fir develop in areas receiving 40 to 60 inches of precipitation. Annual precipitation is from 40 to 50 inches in the vicinity of Shaver Lake, Fresno County, California (lat. 37° 8' N., long. 119° 17' W.) where site conditions appear to be about optimum. Temperature extremes range from -38° F. in Colorado to 98° F. in southern California (32).

EDAPHIC

White fir grows on a great variety of soils. It develops best on moderately deep, rich, moist loam but it is often found on dry, coarse, disintegrated rock and among boulders. Heavy clay soils do not favor its development (32).

1/ The author acknowledges appreciation for valuable help from several reviewers, particularly E. L. Mowat of the Pacific Northwest Forest and Range Experiment Station and C. R. Quick and W. W. Wagener of the California Forest and Range Experiment Station.

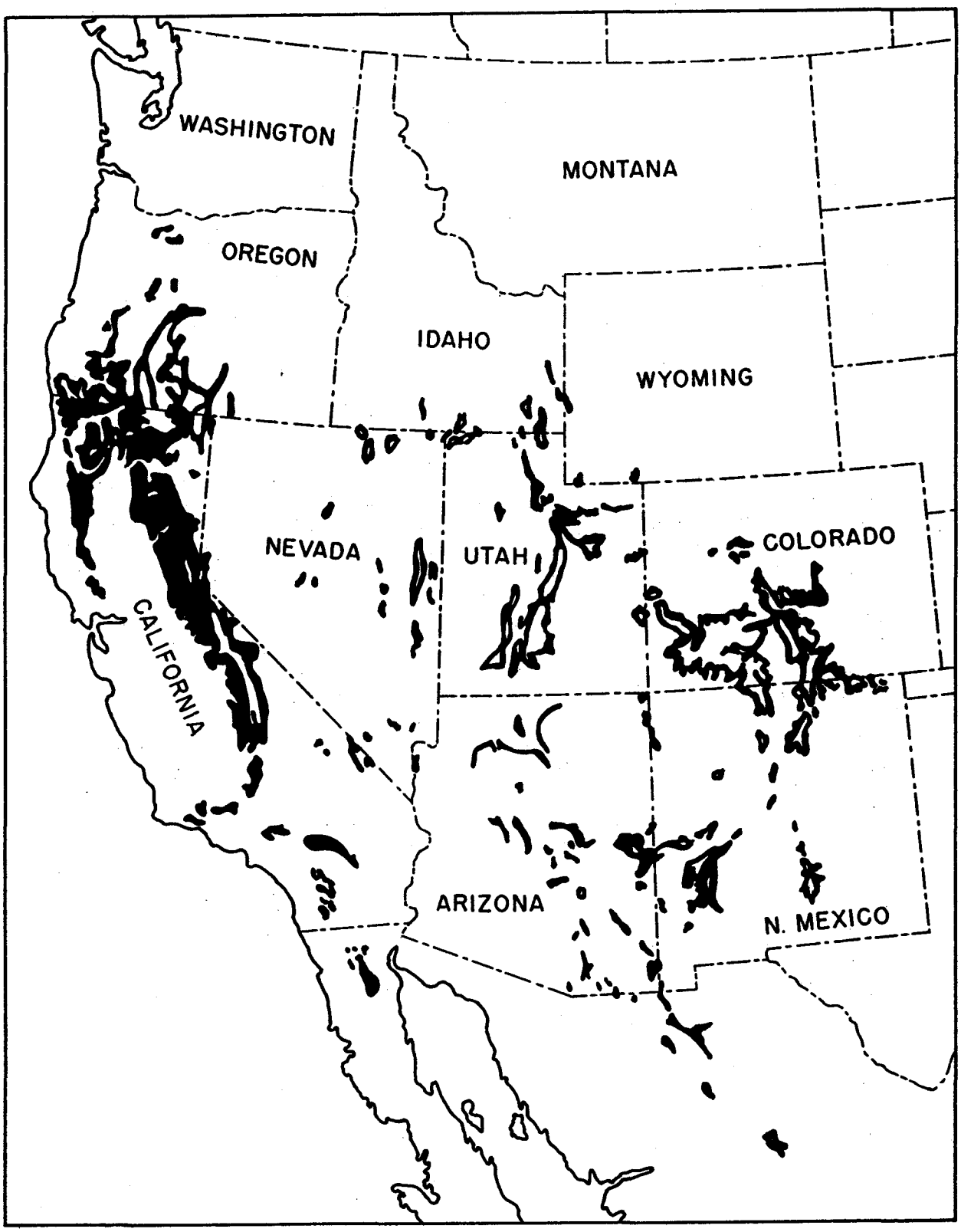

Figure 1.--The natural range of white fir. (Adapted from Munns, E. N. 1938. The distribution of important forest trees of the United States. U. S. Dept. Agr. Misc. Pub. 287, 176 pp., illus.)

Throughout its range, white fir may be found growing on soils derived from a variety of parent materials such as andesite, dacite, diorite, latite, rhyolite, basalt, granite, pumice, sandstone and shale. The deeper and more permeable soils, when supplied with adequate moisture, are most conducive to good growth.

In California 2/ white fir has been found on the Aiken, Holland, Hugo, Olympic, Sheetiron and Sites Soil Series. In northeastern California many stands grow on soils of volcanic origin. In the central and northern Coast Range the species often occurs on the Hugo soils which are derived from sandstone and shale rocks. This series, grayish brown to pale brown in color, is generally of a friable, granular loam structure and is slightly to strongly acid in reaction. In the mixed conifer type of the central Sierra some of the finest specimens of white fir occur on the Holland series. These soils, of a sandy loam or loam type, are developed from weathered granitic and similar quartz-bearing crystalline rock; they are free of lime and predominantly slightly acid.

Good development is also common on soils of the Olympic series. These soils are distributed through the mountains and foothills of the Sierra Nevada, Cascade, and the Coast Range in Oregon and central and northern California. They are developed from basaltic and andesitic rocks and are moderately to strongly acid in reaction. They usually have a friable, granular, clay loam structure.

PHYSIOGRAPHIC

White fir is found over rather widely varying altitudes in its extensive geographical range. Presumably occurrence is governed mainly by temperature extremes, quantity and seasonal distribution of precipitation, and aspect.

In Oregon, it occasionally grows at elevations as low as 2,000 feet on slopes in the headwaters of the Willamette River. Farther south, along the western slopes of the Cascade range, it grows from about 3,000 to 6,000 feet. On the east side of the Cascades, near Mt. Jefferson, it occurs at altitudes of 4,000 to 7,500 feet, and in the Klamath River basin from 5,000 to 7,700 feet (32).

On the west side of the North Coast Range of California white fir is sometimes found as low as 3,000 feet; on the eastside of these mountains, between 4,500 and 7,400 feet. It ranges up to 8,100 feet or more on the higher peaks in the Warner Mountains of northeastern California. In the San Bernardino Mountains of southern California it grows at elevations of from 4,800 to 10,000 feet and is found mostly on north slopes. In Lower California it occurs in the San Pedro Martir Plateau at 8,000 to 11,000 feet (32). The bulk of the white fir in California is found at elevations of 4,000 to 7,000 feet along the western Sierra Nevada.

2/ Information on soils in California was supplied by Robert E. Nelson, California Forest and Range Experiment Station.

In the interior parts of its range, including the Rocky Mountain area and the Southwest, white fir occurs from 6,000 to 11,000 feet, but it is most frequently found at elevations between 7,000 and 9,000 feet. Usually it grows on north slopes and in some localities is fairly abundant on benches and sides of moist canyons (33).

Along the outer ranges of the Rocky Mountains, east of the Continental Divide and south of the divide separating the Platte and Arkansas Rivers, white fir occasionally occurs up to 11,000 feet (24). In the Southwest it is common in ponderosa pine, Douglas-fir, and spruce-fir forests between 5,500 and 10,000 feet (18).

BIOTIC

White fir is represented in 11 forest cover types of Western North America and occurs as scattered individuals, in small groups, or in practically pure stands (30). The white fir type, as such, is found in the Cascade Mountains and in the ranges immediately to the east in Oregon and California. This type often covers fairly large areas. It may be a climax type whether in pure stands or with a light mixture of associates.

Mixtures of California red fir (Abies magnifica A. Murr.) and white fir are common in northern California. Whether in practically pure type, or in heavy mixture with red fir, the stands are often very dense and contain little or no underbrush. White fir is also a prominent species in the ponderosa pine-sugar pine-fir type, often called the mixed-conifer type. White fir often constitutes a transition species at the lower limits of the red fir belt; within the red fir type it is frequently the major associate.

White fir is also found as a minor component in the following cover types: Pacific Douglas-fir, Pacific ponderosa pine--Douglas-fir, Pacific ponderosa pine, California black oak, Jeffrey pine, interior ponderosa pine, interior Douglas-fir, and blue spruce (30).

In the northern part of its range on the Pacific Coast, including Oregon and northern California, white fir is often associated with (33):

P. ponderosa Laws.	ponderosa pine
P. jeffreyi Grev. and Balf.	jeffrey pine
P. contorta Dougl.	lodgepole pine
P. lambertiana Dougl.	sugar pine
Abies magnifica A. Murr.	California red fir
Abies grandis (Dougl.) Lindl.	grand fir
Pseudotsuga menziesii (Mirb.) Franco	Douglas-fir
Libocedrus decurrens Torr.	incense-cedar

Throughout south-central Oregon and northeastern California, forests of ponderosa pine and white fir are common. In the southern part of its Pacific Coast range, which includes central and southern California, and Lower California, Mexico, white fir is associated with ponderosa

pine, jeffrey pine, sugar pine, lodgepole pine, western white pine (P. monticola Dougl.), incense-cedar, red fir, and giant sequoia (Sequoia gigantea (Lindl.) Decne.).

Associated plants and shrubs which commonly occur with white fir in the Pacific Coast region vary according to the altitudinal and latitudinal distribution of the various species. Some of the woody plants that may be present in the different locations include:

Ribes roezlii Regel.	Sierra gooseberry
Ribes viscosissimum Pursh.	sticky currant
Symphoricarpos rotundifolius Gray	roundleaf snowberry
Arctostaphylos nevadensis Gray	pinemat manzanita
Arctostaphylos patula Greene	greenleaf manzanita
Ceanothus integerrimus H. and A.	deerbrush ceanothus
C. parvifolius Trel.	littleleaf ceanothus
C. cordulatus Kell.	mountain whitethorn ceanothus
Castanopsis sempervirens Dudley	Sierra evergreen chinkapin
Chamaebatia foliolosa Benth.	bearmat
Gaultheria shallon Pursh.	salal

Reports that mention white fir east of the Pacific Coast region usually refer to it as a minor component of the forest cover. Its economic importance and abundance diminish greatly as its range extends eastward from the Pacific Coast region.

Throughout the interior parts of the range, white fir never forms pure stands of mature trees over large areas, but frequently forms small nearly pure stands (33). It is most commonly associated with Douglas-fir, less commonly with ponderosa pine, and infrequently with Engelmann spruce (Picea engelmannii Parry) and blue spruce (Picea pungens Engelm.). White fir penetration into the Engelmann spruce-alpine fir or blue spruce types is not nearly as prevalent at the higher elevations in the northern part of its range as it is farther south. In the Southwest it is also found associated with subalpine fir (Abies lasiocarpa (Hook.) Nutt.), and aspen (Populus tremuloides Michx.), and limber pine (Pinus flexilis James) and Mexican white pine (Pinus strobiformis Engelm.) (23).

Some of the more common herbaceous and woody plants which are represented in the ground cover of the interior Douglas-fir are:

Carex spp. L.	sedges
Pteridium aquilinum pubescens Underw.	western bracken
Vicia americana Muhl.	American vetch
Aquilegia spp. L.	columbine
Helenium Hoopesi Gray	orange sneezewood
Sambucus spp. L.	elder
Ribes spp. L.	currant or gooseberry

Snowberry (Symphoricarpos spp. L.) and Fendler ceanothus (Ceanothus fenderli Gray) occur only in small areas receiving sufficient sunlight. Underbrush and aspen are common in the areas thinned by fire. Forests of the Engelmann spruce-alpine fir and blue spruce types are often dense and shrubs and grasses are practically absent (22).

LIFE HISTORY

SEEDING HABITS

Flowering and Fruiting

White fir cones mature in a single growing season. The species generally flowers in May or June and the cones ripen in September or October (35). Seed-bearing or ovulate conelets occur as erect, individual bodies on the uppermost branches of the crown. Elongated staminate conelets bearing the pollen are suspended on the underside of the branches below the level of ovulate flowers. Both male and female conelets are found on branchlets formed in the previous year (3). Staminate conelets drop shortly aften pollen release. Seed-bearing cones grow to a length of 3 to 5 inches and mature as closely packed cylinders of cone scales. Each cone scale covers two seeds (5).

Mature seeds consist of a thin, rather soft seed coat with several resin vesicles on its surface, and an embryo with 4 to 10 cotyledons surrounded by a fleshy endosperm (35).

The overlapping cone scales fall away from the central spike-like axis during the period of seed dispersal; consequently, no cones are found on the ground under the trees except for immature or ripening cones which have been cut by squirrels.

The time of flowering and cone ripening of white fir varies somewhat, depending upon annual variations in the seasons and different climatic conditions throughout the range of the species. On the Stanislaus National Forest in the central Sierra Nevada, California, at about 6,000 feet, Fowells and Schubert (11) found that the pistillate strobili of white fir were first discernible in early May. By middle or late May the conelets were about 1 inch long. Pollen was disseminated during the last half of May. Some conelets were killed by severe frosts during May and early June. The cones were about 2 inches long by the first of July and full size was attained in early August. Seeds averaged about 185 per cone. Cones began to disintegrate and shed seeds in late September or early October.

Seed Production

A 28-year study of seed production, chiefly in the central Sierra Nevada, showed that individual white fir trees did not produce cones every year and relatively few had cones every other year (11). Cone crops occurred at irregular intervals, and heavy cone crops

were produced at from 3 to 9 year intervals, the average being about 5 years. Relatively small proportions of white fir seeds were sound, even in good seed years; viability ranged from 4 to 57 percent.

Amount of seed production was also found to vary with dominance and tree size. In one study, 88 percent of the white fir cones occurred on dominant trees, 12 percent on codominants, and almost none on the intermediate and suppressed trees. Trees from 12 to 36 inches d.b.h. were the best cone producers. Cone production reached a peak at about 30 inches and then gradually diminished as diameter increased. Trees with a diameter range of 22 to 34 inches averaged about 65 cones annually, while those with a 10 inch diameter averaged 30 to 35 cones (11). The minimum seed-bearing age for white fir has been reported to be 40 years, and optimum cone production to be from 50 to 100 years (35).

The maximum number of cones reported on an individual tree was 987 on a 25-inch tree; this is equivalent to about 190,000 seeds weighing 12-1/2 pounds (11). The Woody-Plant Seed Manual (35) states that a bushel of cones yields from 3 to 5 pounds of cleaned seed which average 15,000 seed per pound.

In the Rocky Mountain area white fir has good seed years at irregular intervals of 2 to 4 years (33). Seed bearing continues for many years but is more abundant during the period of rapid height growth (between ages of 50 and 100 years). Pole-size trees in dense stands usually bear seeds only when their leaders reach full sunlight.

Because cones are borne almost exclusively in the uppermost part of the crown, any tree-top damage caused by insects, diseases, and mechanical agents such as ice, snow, or wind, directly reduces cone production. Fowells and Schubert (11) found that white fir in the larger diameter classes frequently bore relatively few cones because of crown decadence caused by fir mistletoe (Phoradendron pauciflorum Torr.) and western dwarfmistletoe (Arceuthobium campylopodum forma abietum (Engelm.) Gill.). Some tops were also killed by the fir engraver beetle (Scolytus ventralis Lee.). However, trees which had lost their tops sometimes developed new terminals and resumed cone bearing.

Seed chalcids (Megastigmus spp.) often damage white fir seed, and the poor quality of much of the seed is attributed to infestations of these insects (11); no practical way of preventing damage by seed chalcids has been found (13). Fir-cone moths (Barbara spp.) often seriously injure cones (13); considerable damage to cones is also attributable to the cone maggots (Earomyia spp.) which bore through cone scales and seeds.

Rodents and birds sometimes eat white fir seed. The Douglas pine squirrel (Tamiasciurus douglasii Bachman) in California has been

observed cutting white fir cones and storing them in fairly large caches. When both ponderosa pine and white fir cones were available, squirrels exhibited a greater preference for ponderosa pine (11).

Seed Dissemination

Seeds are disseminated mostly by wind and to a very minor extent by rodents. In general, seed dissemination begins in September and continues through October, but the timing varies with elevation and climate; some cones, apparently sealed with resin, remain intact until December or later. One study (11) in California found that seeds fell irregularly during the autumn and not all seeds were shed during the autumn months; seeds were observed on the snow in midwinter, suggesting that either cones disintegrate slowly or seeds temporarily lodge in the foliage before sifting down.

White fir seed has a relatively short, broad wing for its weight and consequently falls more rapidly than seeds of pines and spruces, which have wings much longer than their width. Sound white fir seeds average about 0.070 gram in weight and, in still air, fall at a rate of 5.7 feet per second (29).

Computations based on work by Siggins (28) and assuming smooth air flow, show the following theoretical horizontal flight distances for white fir seed:

Average wind speed, m.p.h.:	Height of seeds in tree		
	50 ft.	100 ft.	150 ft.
5	64	128	193
10	128	256	385
15	193	385	513
20	257	513	770
25	322	644	967

The greatest number of seeds usually fall close to the base of the tree. Seed dissemination is influenced by many factors--weight of individual seeds, height of tree (especially important in white fir which bears cones in the upper crown), surrounding or adjacent forest canopy, terrain, updrafts, air turbulence, and direction of prevailing winds.

In one study of seed production and dissemination in a mixed-conifer stand in the central Sierra Nevada, white fir seeds fell at the rate of 223,000 per acre, including sound and unsound seed (11). This amount would be considered a very high rate of seed dissemination even if only half the seed were sound.

VEGETATIVE REPRODUCTION

White fir shows no natural tendency to reproduce by sprouting or layering.

SEEDLING DEVELOPMENT

Germination and Establishment

White fir seeds germinate in the spring. Germination is epigeous (cotyledons appear above the ground). Usually not more than 50 percent germinate, owing to dormancy of the embryos, high percentage of seed injury during dewinging, insect infestation, and the transient viability of the seed (35).

The species will grow rather readily on a variety of natural seed beds. Moist humus or mineral soil under partial shade form equally good natural seed beds. Heavy litter is less of a hindrance to white fir than to ponderosa pine.

One recent study in the sugar pine-fir type in the Sierra Nevada of California revealed that, in clear-cut openings, more white fir than sugar pine seedlings died within 2 years (26). For the 2-year period the total mortality was 45 percent for sugar pine and 73 percent for white fir.

Selective cutting in mixed-conifer forests in California tends to favor regeneration of white fir, especially if advance reproduction of the species is present. Even in dense brush, white fir seedlings eventually overtop and suppress the shrubby growth. White fir seedlings are sometimes more abundant than ponderosa pine under a predominantly pine canopy whose shade and litter excludes its own seedlings (7). Generally, under the closed canopy of a predominantly pure white fir stand, seedling development is absent or sparse.

One of the requisites for white fir establishment is available surface soil moisture at germination time. Moisture and suitable temperature for germination go hand in hand. In the Southwest, the early drought period often hampers seedling development. In Colorado and northern New Mexico the summer drought is less pronounced, but winter killing becomes an important cause of mortality (23).

Early Growth

Growth of white fir is usually exceptionally slow up to about 30 years of age; then growth accelerates markedly. The protection of advanced reproduction in the early period of growth is essential if set-backs in establishment are to be avoided.

In the Klamath basin of Oregon, white fir in about a 25 percent mixture with ponderosa pine was often found to be about 5-1/2 feet in height at 30 years of age (15).

In the Sierra Nevada, white fir seedlings in openings made slow height growth in the early years of development and ranged from 0.2 to 2.3 feet in total height for an 8-year period (26).

The average height was only 0.6 feet. Jeffrey pine averaged 4.3 feet, during this period, sugar pine 2.9 feet. The difference in height growth was not all due to inherent growth characteristics. Late spring freezes had damaged the new growth on white fir. Temperatures below 20° F. completely destroyed the new growth. The only seedlings which encountered little or no damage were those sheltered by other vegetation such as shrubs and pines. Damage to white fir seedlings by deer browsing also was fairly severe. This study suggests that white fir regeneration in clearings may be slow and uncertain.

SEASONAL GROWTH

Seasonal growth of white fir and associated species was studied for 8 years on the Stanislaus Experimental Forest at 5,200 feet elevation, in the Sierra Nevada of California. Other species were: Jeffrey pine, lodgepole pine, ponderosa pine, sugar pine, and incense-cedar. The average starting date for seasonal height growth in white fir was June 24, a month to 6 weeks later than the average starting dates for the associated species. Height growth was completed in 46 days, on the average this period was 5 days shorter than for sugar pine, which had the next shortest height growth period among the other conifers (10).

Seasonal radial growth of white fir began before seasonal height growth. Of the six species studied, white fir had the shortest period of seasonal radial growth and was the last to start. Radial growth continued for a longer period than height growth (11).

SAPLING STAGE TO MATURITY

Growth and Yield

White fir reaches its best growth development in the Pacific Coast region, especially on some of the better sites in California. There good sites are found with either minor or major occurrence of white fir in mixture, as well as in the predominantly pure white fir type. Much of the remaining white fir in California is found in old-growth stands and growth information on young-growth stands is meager.

On the better sites in the Pacific Coast region, mature trees range from 140 to 180 feet in height and from 40 to 60 inches in diameter; occasional trees exceed 200 feet in height and 72 inches in diameter. Out of 951 white firs on which ages were counted on 7 study areas in California and southern Oregon, none was older than 360 years and only 3 were in the 341- to 360-year age class. 3/ In Yosemite National Park, California, a few white firs of very large diameter are older than 500 years (4). One large specimen in

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3/ Information supplied by W. W. Wagener, California Forest and Range Experiment Station.

Yosemite reached a height of 189 feet and a diameter slightly larger than 8 feet (1). Trees 6 feet in diameter often contain from 13,000 to 17,000 board-feet, Scribner log rule.

Dominant white fir trees in California grow at about the same rates as ponderosa pine, sugar pine, and Douglas-fir throughout most of their life span. Dunning (8) found this from his studies that led to development of a site classification for the mixed-conifer forests of the Sierra Nevada. He concluded that growth differed so little that dominants of any of the four species could be used for applying the height-age curves. He stated: "Sugar pine is, if anything, slightly taller than the other species at comparable ages, but the differences between the four species are not large or consistent enough to be accepted as significant or important." At the chosen index age of 300 years, the average height of dominants on the best site is 200 feet and on the poorest site only 75 feet (fig. 2). The range in heights at this age is thus very great. At the age 100 years, the range is from about 140 feet down to 52 feet.

Schumacher (27) also studied the relationship between heights of dominant white firs and associated species in California. His findings indicated that ponderosa pine and red fir grow at practically the same rate as white fir on the same sites and within the age limits of the data (45 to 150 years), but sugar pine grows somewhat more slowly. Data for Douglas-fir were inadequate to give a definite conclusion, but its growth appeared to be intermediate between that of white fir and sugar pine.

In fully stocked stands, white fir attains high basal area stocking rather quickly (27):

Age, years:	Basal area per acre where site index at 50 years is: 90 feet (sq. ft.)	60 feet (sq. ft.)	30 feet (sq. ft.)
50	316	265	166
100	471	397	249
150	471	397	249

Yields from fully stocked stands in California at age 100 years have been predicted to be 147,800 board-feet per acre on the best sites and 74,000 board-feet on average sites (27). Though such idealistic conditions are unlikely to be duplicated on large areas, the figures show that white fir is capable of exceedingly high production. A mixed stand of mature (200 to 300 years) white and red fir on Swain Mountain Experimental Forest in northeastern California averaged 92,000 board-feet per acre over an area of about 120 acres, and a small part of this area averaged 147,000 board-feet per acre.

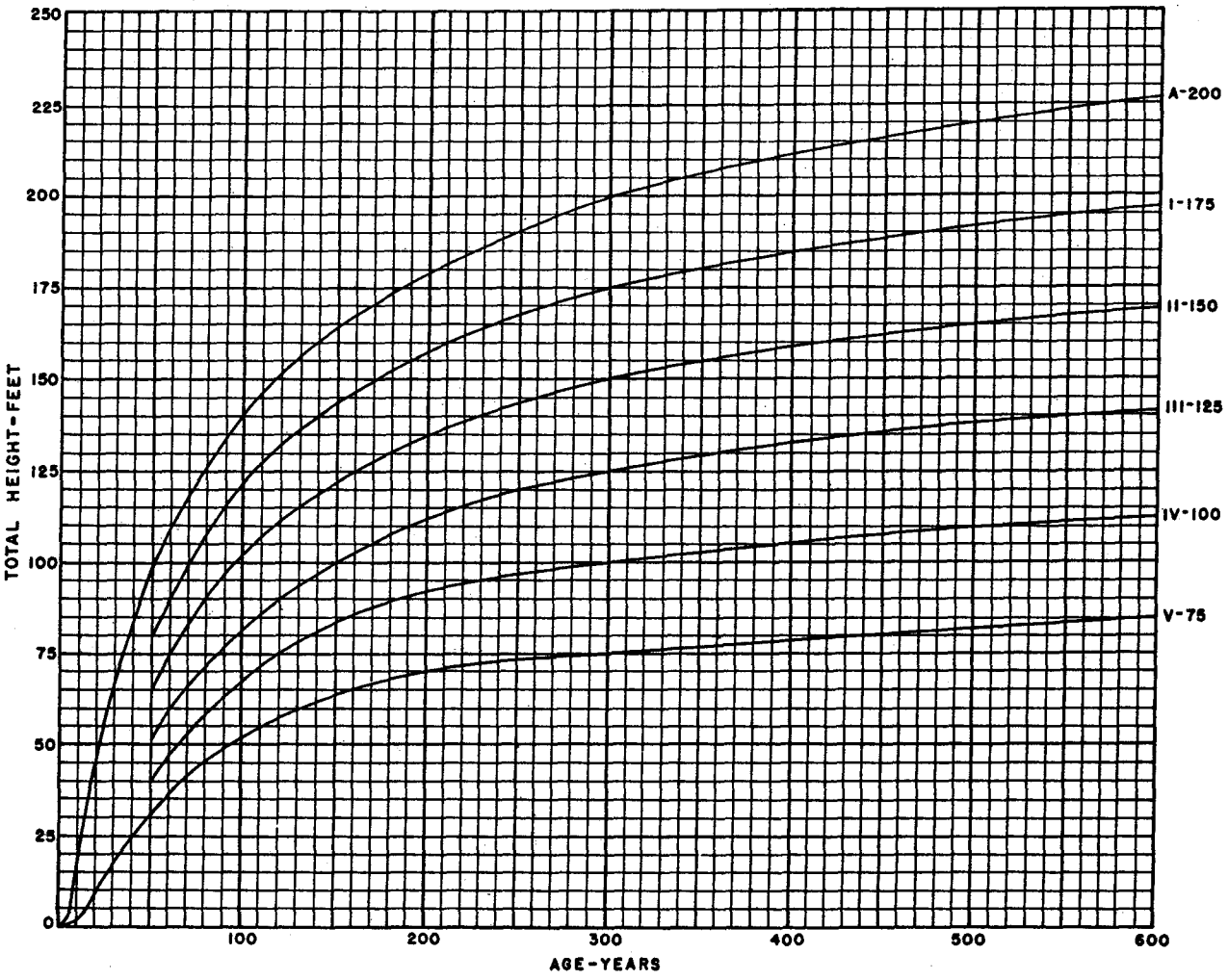
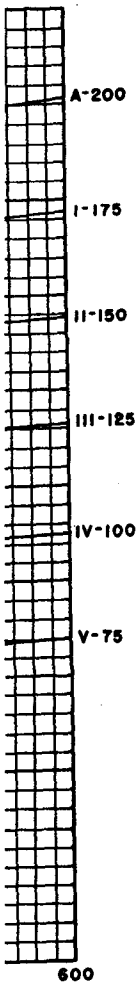


Figure 2.--Height-age site classification curve for the mixed conifer selection forests of the Sierra Nevada (8). (Site classification based on total height of dominants of one or more of the following species: Sugar pine, ponderosa pine, Douglas-fir, and white fir at age 300 years.)



From a study of even-aged white fir plots in California, Schumacher (27) prepared the following stand data:

Site Index 90 feet for White Fir 1/
(Includes trees 8 inches and over)

Age, years:	Trees per acre (number)	Ave. height (feet)	Ave. d.b.h. (inches)
60	275	100	15.6
80	238	114	18.6
100	198	122	20.8
120	172	127	22.3
140	155	130	23.5

1/ Based on average dominant white fir of 90 feet at 50 years of age.

Site Index 60 feet for White Fir 1/
(Includes trees 8 inches and over)

Age, years:	Trees per acre (number)	Ave. height (feet)	Ave. d.b.h. (inches)
60	351	70	11.8
80	331	80	14.1
100	287	86	15.6
120	259	89	16.5
140	240	91	17.2

1/ Based on average dominant white fir of 60 feet at 50 years of age.

In the Klamath Basin of Oregon, white fir dominants at age 200 average from 110 to 120 feet in height and about 24 inches in diameter (15). Kerr (15) found that white fir attained a maximum diameter growth of 0.17 inch per year at about 100 years of age. Beyond this age, diameter growth diminished to 0.11 inch per year at 250 years of age. Such growth conditions probably would be somewhat similar to white fir development on the better sites of the Rocky Mountain area.

In the interior and Rocky Mountain parts of its range, white fir is seldom more than 125 feet in height, and diameters rarely exceed 3 feet (24). The largest trees probably range from 250 to 275 years of age (33). In these interior regions, white fir does not reach the size or age of trees in the Pacific Coast region.

Ages, diameters and heights of white fir occurring in the Carson National Forest of New Mexico (22, 23) were:

Age (years)	D.B.H. (inches)	Height (feet)
40	1.7	8
60	4.2	18
80	6.9	30
100	9.1	41
120	10.9	49
140	12.2	55
160	13.5	60
180	14.8	65
200	16.2	69
250	19.6	76

Trees 40 to 140 years of age ranged from 7 to 22.2 inches d.b.h. on the former Crook National Forest in Arizona (22).

Natural pruning of branches is slow, especially in young trees. One study (6), found that epicormic sprouts developed 1 to 2 years after trees were artifically pruned; an average of 6 sprouts appeared per tree. Epicormic branches were also found on injured trees. Therefore white fir should not be pruned unless an effective method for control of epicormic sprouting is found.

Reaction to Competition

On sites favoring its establishment, white fir has usually proved a formidable competitor with associated species. In the mixed-conifer stands of California, heavy cutting of fir to favor other species changes future stand composition very little. Usually enough small and otherwise unmerchantable firs remain on the cutover areas to supply abundant seed. Light cuts plus heavy litter, brush, and ground cover favor fir more than pine. If heavy cutting and fire do not occur in mixed stands, white fir maintains its position unusually well (7).

White fir is rated from tolerant to very tolerant, tolerance remaining strong from seedling stage to maturity (2). However, young growth which endures heavy shade and suppression for long periods grows very slowly. In the Rocky Mountain region the tolerance is reportedly greater on moist sites. There, it is more tolerant than any of its associates except subalpine fir (Abies lasiocarpa (Hook.) Nutt.) and Engelmann spruce. It is capable of enduring more shade from the seedling stage to the pole stage than during later stages of growth (33).

Since white fir is less drought resistant than ponderosa pine, it frequently relinquishes its position to pine on the lower, drier

sites in the Rockies. However, throughout its range, white fir often occurs on comparatively dry habitats and is considered to be fairly drought resistant. It is about as drought-hardy as Rocky Mountain Douglas-fir (33).

White fir occurs in both even-aged and uneven-aged groups. In the Pacific Coast region, when growing in mixture with red fir, the stands are often even-aged. White fir is considered to be more shade tolerant than red fir.

Principal Enemies

Because of the notably slow growth of white fir in early youth, protecting established reproduction from damage by logging or fire is of paramount importance if the stand is to fully utilize the growth potential of the site. In early youth the species is easily killed or injured by fire; older trees with thicker bark are more fire resistant. In the high Sierra where snowfall is exceptionally heavy, young trees are often severely damaged by heavy snow.

Old-growth stands of white fir often have a substantial incidence of disease, wind shake, and rift crack. Internal rift cracks (17) arise from internal growth stresses. In white fir these cracks usually spiral, causing cull or serious degrade in the lumber. Sour-smelling water often collects in the lower part of rift cracks and runs out through saw cuts when the trees are being felled. Where temperatures become cold enough to freeze the heartwood, imprisoned water in such cracks is apparently an additional cause of frost crack in the lower bole.

From a preliminary study, Meinecke (20), concluded that pathological defect would limit the rotation to 150 years in the area west of Klamath Lake, Oregon. However, according to Wagener 4/ both growth rate and disease incidence vary widely in the species in different subregions, and it seems doubtful whether any one particular rotation age should be suggested. He suggests that, in most of the Pacific Coast region, disease will not limit the rotation in young-growth white fir. Virgin white fir on the west slope of the Sierra Nevada is more sound than in Oregon, and the new stands coming on will be still more sound because of the increased protection from fire wounds during the last 50 years.

White fir is more subject to windthrow than is ponderosa pine. In some mixed stands which have received heavy selective cuts, severe damage to residual white fir has occurred from uprooting of trees and the breaking of stems at points 10 to 30 feet above the ground.

4/ Personal communication from W. W. Wagener, California Forest and Range Experiment Station.

Wagener 5/ states: "Windthrow in old-growth white fir left as scattered individuals in an otherwise clear-cut stand is often intensified by root rot from Fomes annosus (Fr.) Cke. that has become established through old fire wounds and has developed as a butt rot. Except in pumice soils, the danger of windthrow in second-growth stands should not be unduly high because of the reduction in numbers of fire-wounded trees brought about by fire protection."

White fir is subject to attacks by bark beetles and insect defoliators. The fir engraver beetle (Scolytus ventralis Lec.) sometimes causes severe damage as well as mortality to white fir particularly in California and Oregon (31). The grand fir bark beetle (Pseudohylesinus grandis Sw.) sometimes causes damage when it attacks the trunks or limbs of weakened or dying white fir (13).

The Douglas-fir tussock moth (Hemerocampa pseudotsugata McD.), a defoliator, often causes much damage. Epidemic numbers are sometimes reached by this insect when feeding on the true firs or Douglas-fir. The spruce budworm (Choristoneura fumiferana Clem.) is another one of the more destructive defoliators attacking the true firs and Douglas-fir and often causes great damage in pure stands of these species. The New Mexico fir looper (Galenara consimilis Hein.) has also damaged white fir in the southern Rocky Mountain region, especially in New Mexico. From 1946 to 1948 white fir in Bryce National Park, Utah was considerably damaged by the white fir needle miner (Epinotia meritana Hein.) (13).

In one study in California (9), damage to white fir seedlings from cutworms (Noctuidae) was as high as 34 percent; the damage continued 1 to 2 months after germination. Damage was often more severe in cutover stands than in virgin timber.

White fir is attacked by many other insects of lesser importance.

Heart-rot fungi cause extensive damage in white fir. The principal trunk rot on the Pacific coast is from Echinodontium tinctorium E. and E. which enters almost exclusively through branch stubs and open knots. Butt rots, which may extend up in the trunk for as much as 40 feet are chiefly from Fomes annosus (Fr.) Cke., Pholiota adiposa Fr. and Armillaria mellea (Vahl.) Quel; entrance is principally through fire scars and basal wounds. Limited amounts of decay enter through broken tops, bole wounds, and mistletoe cankers. Frost cracks, common in white fir, often serve as entrance points for damaging fungi. 5/ The cull percentage in white fir in northwestern California may run as high as 30 to 50 percent (16).

5/ Personal communication from W. W. Wagener, California Forest and Range Experiment Station.

Fir mistletoe (Phoradendron pauciflorum Torr.) commonly kills the upper portions of the crowns of white fir in Arizona and in the Sierra Nevada. This mistletoe is limited in range by temperature and does not occur north of the Mokelumne drainage in the Sierras (36). Fir dwarfmistletoe (Arceuthobium campylopodum forma abietinum (Engelm.) Gill) is often found in white fir, and results in deformed tops or crowns as well as swellings in the trunk, which often become decayed. Mistletoe damage may be severe and extensive.

Other diseases deserving of mention include canker from Cytospora abietis Sacc. which may kill branches or entire trees up to pole size east of the Sierra Nevada divide in California and probably elsewhere within the inland range of white fir (37). Damage is particularly severe after late fall drought.

Two needle diseases, from Hypoderma robustum Tub. and Hypodermella abietis-concoloris (Mayr) Dearn., are sometimes severe on young white firs. They have occasionally ruined prospective Christmas tree crops.

In the Rocky Mountains, witches brooms from the rust Melampsorella caryophyllacearum Schrvet. are sometimes prevalent and damaging on white fir.

In northeastern California, "wetwood" resulting from sap fermentation is common in the butt heartwood of white fir. Freezing of this wetwood results in multiple checking of the affected heartwood, often rendering the butt unmerchantable. 6/ Sapling and pole-size white firs are subject to sunscald when suddenly exposed by logging or other agents. Trees with sunscald do not die immediately but succumb 2 to 10 years later--usually as a result of insect infestation following the injury. Trees larger than small pole size, with bark too thick to be killed by sudden exposure, commonly put out secondary crowns after exposure. These crowns arise from epicormic buds. The same thing occurs after pruning but usually is not as extensive.

Many young trees in the 0.5 to 6.0 foot height class die after being severely bent during logging. These trees will succumb a year or two later, even though they may show only superficial injury at the time of logging. In contrast, young pines similarly bent usually recover. Such delayed mortality of young firs was noted particularly on sampling strips set out by forest disease research workers in 1927-1928, in logging slash on Logan Mountain in northeastern California. 6/

In the Klamath Basin of Oregon, the tops and upper branches of white fir are sometimes girdled by porcupines (Erethizon dorsatum Linn.) (15). Seed destroying agents are discussed in the section on Seed Production.

6/ Personal communication from W. W. Wagener, California Forest and Range Experiment Station.

SPECIAL FEATURES

White fir was first reported in 1847 near Santa Fe, New Mexico by a Russian plant collector, August Fendler. John Jeffrey discovered it on the Pacific slope in northern California in 1851 (33).

White fir is used as an ornamental tree in the eastern United States from Virginia north into New England and in Europe. It is particularly adapted to landscape planting because of its dense symmetrical crown and ability to stand heavy shade (5). In California and Oregon, the commercial harvesting of white fir for Christmas trees is of considerable importance. Bark of older trees contains a cork-like material.

Most of the bear dens discovered in Yosemite National Park, California are found in white fir, supposedly because they like to build their dens in the soft decayed heartwood of the older white firs (4).

RACES AND HYBRIDS

In the Cascade mountains of southern Oregon, white fir is found associated with grand fir (Abies grandis Lindl.), and some intermediate hybrid forms of these two firs are known but specific identification of these intermediate forms is often difficult (12). A natural hybrid between Abies concolor and A. grandis has been reported from an arboretum in Germany (25). Nine varieties are listed in Standardized Plant Names (14).

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