Abies concolor (Gord. & Glend.) Lindl. ex Hildebr. **White Fir**

Pinaceae Pine family

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Long considered undesirable for timber, white fir *(Abies concolor)* is finally being recognized as a highly productive, valuable tree species. White fir reaches its best development and maximum size in the central Sierra Nevada of California, where the record specimen is 58.5 m (192 ft) tall and measures 271 cm (106.6 in) in d.b.h. (7). Large but not exceptional specimens, on good sites, range from 40 to 55 m (131 to 180 ft) tall and from 99 to 165 cm (39 to 65 in) in d.b.h. in California and southwestern Oregon and to 41 m (134 ft) tall and 124 cm (49 in) in d.b.h. in Arizona and New Mexico (37).

Needle form and terpene content vary sufficiently across the wide range of the species to warrant definition of two varieties: the typical var. ***concolor,*** white fir, often called Rocky Mountain white fir, occupies the eastern and southwestern part of the range; var. *lowiana* (Gord.) Lemm., California white fir, grows in the western range ***(31).*** In this paper, "white fir" applies to both varieties.

Habitat

Native Range

The native range of white fir (fig. 1) extends from the mountainous regions of the Pacific coast to central Colorado, and from central Oregon and southeastern Idaho to northern Mexico (21).

Climate

Rocky Mountain white fir grows on high mountains, typically with long winters, moderate to heavy snowpacks, and short growing seasons. Annual precipitation ranges from about 510 mm (20 in) to slightly more than 890 mm (35 in). In the central Rocky Mountains, rainfall is distributed evenly during the summer months. In Arizona and New Mexico, summer tends to be wetter than spring (37).

California white fir grows in cold, high elevations and in warm-to-hot low elevations. Precipitation ranges from 890 mm (35 in) to 1900 mm (75 in) or more per year. California white fir grows best in the southern Cascades and western slopes of the Sierra Nevada, where precipitation is generally between 990 and 1240 mm (39 to 49 in). Locations receiving 1500 mm (59 in) or more are not uncommon, however ***(21).*** Essentially, all precipitation occurs during the nongrowing season. Fall and early spring rains are a major portion of the precipitation at lower elevations and winter snowpacks provide more than 80 percent of the moisture at high elevations (57). Occasional summer thundershowers are usually light.

Growth studies on Swain Mountain Experimental Forest, in the southern Cascades of California, indicate that high-elevation stands of California white fir grow best in years with precipitation as low as 38 percent of normal (45). At these elevations low precipitation usually means early snowmelt and a longer growing season (54).

Soils and Topography

Throughout its natural range, white fir grows on a variety of soils developed from almost every kind of parent material. These materials include recent volcanic and igneous rocks of nearly all compositions, large areas of intrusives (mostly granites), and various metamorphics, including serpentine. Sedimentary materials range from limestone, sandstone, and shale to unconsolidated Pleistocene lake deposits *(5,21,22).* These soils fall into the Inceptisol, Entisol, Alfisol, and Ultisol soil orders. Alfisols are most frequently found at the lower elevations in California where white fir is a component of the Sierra Nevada Mixed Conifer Type.

White fir is generally tolerant of a wide range of soil conditions, nutrient availability, and pH values. It seems to be more dependent on moisture availability and temperature than on soil series. In at least one area of summer-dry Mediterranean climate, productive stands of white fir may utilize water obtained from shattered or otherwise porous bedrock well below the maximum soil depth (8). Growth and development are best on moderately deep and well-drained sandy-loam to clay-loam soils, regardless of parent material. High-elevation fir forests respond strongly to nitrogen fertilizer because low temperatures inhibit decay and natural release of nitrogen from the forest floor (49).

California white fir is moderately sensitive to excess soil moisture and invades high-elevation meadows by growing near older lodgepole pine, taking advantage of relatively dry ground created by the pine roots. A similar pattern of meadow invasion can develop where radiational heat loss on clear, cold

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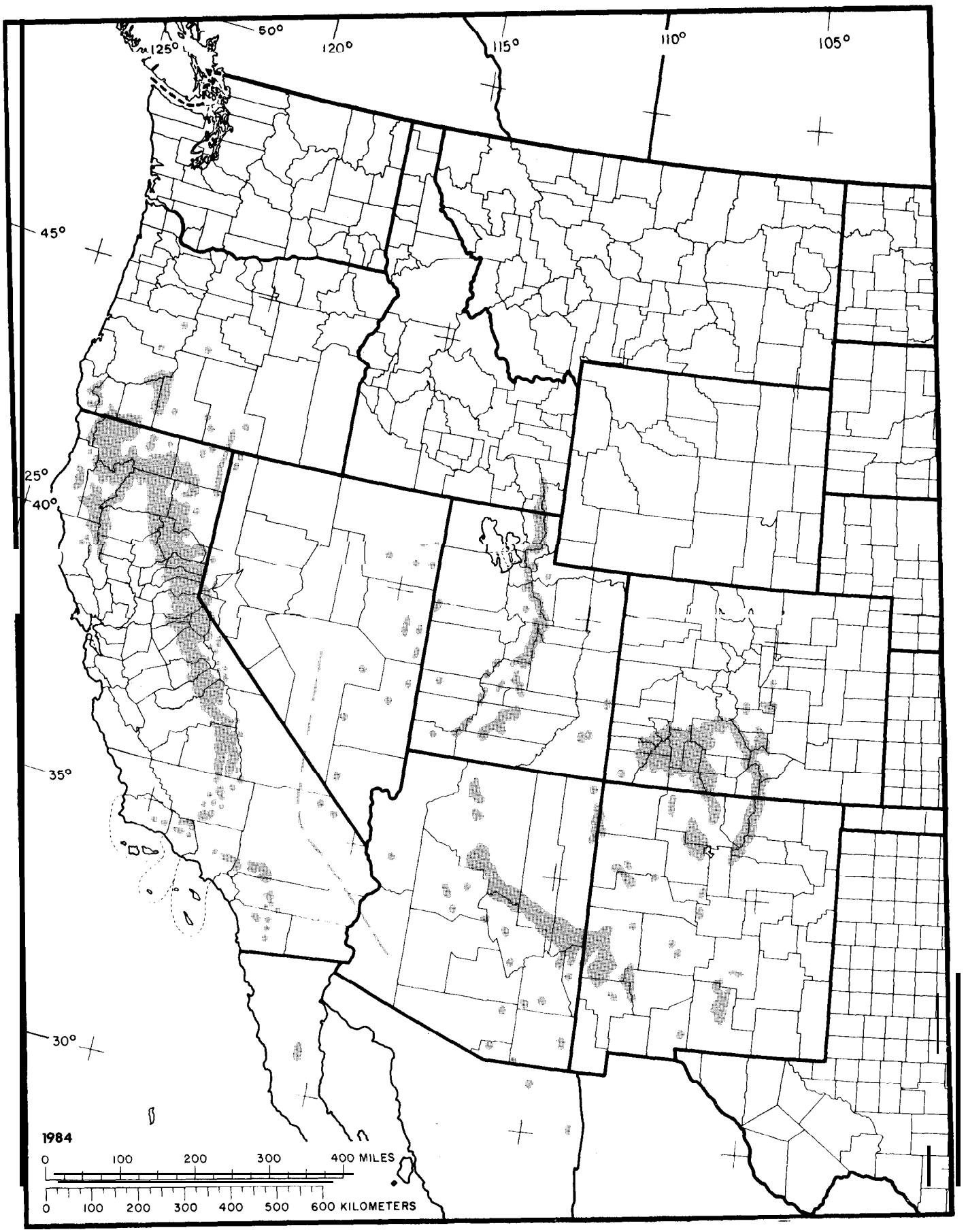

Figure 1—*The native range of California white fir (left) and Rocky Mountain white fir (right).*

nights is significant. In these situations, the frost-sensitive fir is protected by the pine foliage.

The species grows on various types of terrain, including the extremely steep and unstable slopes of the geologically young Coast Ranges in northwestern California. It develops best on gentle slopes and level ground. Elevations range from a minimum of 600 m (1,970 ft) in the headwaters of the Willamette River of central Oregon to a maximum of almost 3400 m (11,150 ft) east of the continental divide in central Colorado. Lower and upper elevational limits increase from north to south and from west to east as temperatures, distance from the Pacific Ocean, or both increase. Most California white fir in the Sierra Nevada is found at elevations between 1200 and 2100 m (3,900 and 6,900 ft). It grows at elevations of 1500 to 3000 m (4,900 to 9,800 ft) in the San Bernardino Mountains of southern California. Rocky Mountain white fir is found most frequently at elevations between 2100 and 2700 m (6,900 and 8,900 ft) *(21,22,47)*.

Associated Forest Cover

The most common associates of California white fir in the mixed conifer forests of California and Oregon include grand fir ***(Abies grandis),*** Pacific madrone ***(Arbutus menziesii),*** tanoak ***(Lithocarpus densiflorus)***, incense-cedar ***(Libocedrus decurrens),*** ponderosa pine *(Pinus* ***ponderosa),*** lodgepole pine *(P.* ***contorta),*** sugar pine *(P.* ***lambertiana),*** Jeffrey pine *(P.* ***jeffreyi),*** Douglas-fir ***(Pseudotsuga menziesii),*** and California black oak *(Quercus* ***kelloggii)*** *(21,47)*. In the central Sierra Nevada, white fir is a major associate of the relatively rare giant sequoia (*Sequoiadendron giganteum)* ***(21).*** Species mix varies with elevation, site, and latitude. White fir is more abundant on the cooler, wetter sites.

Figure *S-Small woodland meadow* **at** *1920 m (6,300 ft) in a California white +-California red fir forest. Downed log in foreground and trees in background are lodgepole pine.*

California white fir is a major climax component throughout the mixed conifer forests within its range. It is displaced successionally only at its northern limits in Oregon, where western hemlock *(Tsuga* ***heterophylla)*** and perhaps western redcedar *(Thuja* ***plicata)*** replace white fir as a climax species on moister sites (22). At the upper elevational limits of the mixed conifer forest, white fir dominates, occasionally forming pure stands. Still higher, white fir mixes with California red fir (A. *magnifica)* in transition to the red fir type. In the southern Sierra Nevada, white fir in this transition zone generally tolerates canopy closure better and dominates on nutrient-rich sites (46). Lodgepole pine is common in these white fir and mixed fir forests, growing around meadows and along streams (fig. 2). Individuals of Jeffrey pine, western white pine *(P.* ***monticola),*** and sugar pine are scattered through the forest (47). In Oregon, scattered western hemlocks are also found *(22)*.

At low elevations California white fir is an aggressive, tolerant species that appears to have been held in check by frequent natural fires. Extensive fire control efforts, however, have reduced fire frequency. As a result, white fir is becoming a major stand component in California at elevations and on sites where originally it was minor (48). Dense fir regeneration beneath older stands of less tolerant trees is common and threatens a major change in species composition. In many places, especially with giant sequoia, such changes are undesirable, and control measures, including reintroduction of fire, are necessary.

In Arizona and New Mexico, Rocky Mountain white fir (fig. 1) is a major climax component in 11 major habitat types and phases (42). Listed in sequence-from warm and dry low-elevation to cool and moist high-elevation environments-these habitat types include ponderosa pine/Arizona fescue, white fir/Arizona fescue, white fir-Douglas-fir, white fir–Douglas-fir/Gambel oak, white fir-Douglas-fir/Rocky Mountain maple, and blue spruce-Engelmann spruce/forb *(Senecio* spp.). White fir is a minor climax component in the Douglas-fir-southwestern white pine/grass ***(Muhlenbergia*** spp.), blue spruce–Douglas-fir, and blue spruce/sedge *(Carex* spp.) habitat types. Additional associates are subalpine and corkbark firs. Aspen ***(Populus tremuloides)*** is a major seral species in many areas.

A variety of woody brush species can assume major importance in much of the white fir range, particularly in mixed conifer zones. Following drastic disturbance, brush can quickly occupy and dominate a site. Common species include mountain whitethorn, deerbrush, and other Ceanothus species, manzanita *(Arctostaphylos* spp.), currant and gooseberry *(Ribes* spp.), several chinkapins *(Castanopsis* spp.), and a few oaks *(Quercus* spp.) *(21,22).* In addition to severely competing for light and moisture *(14)*, at least one *Ceanothus* species contains allelopathic chemicals in its foliage that suppress radicle growth of white fir *(12).* Mycorrhizal associations are thought to protect white fir roots from allelopathic chemicals produced by bracken fern *(Pteridium aquilinum) (1).* Other species of lesser vegetation that sometimes assumes a significant role includes bearclover *(Chamaebatia foliolosa)* and several grasses. Seeds of some species can lie dormant in the forest floor for as long as 300 years and germinate following removal of forest cover by fire or harvesting. In areas where brush is vigorous, tree seedlings that can survive and grow under brush cover are favored, provided the time between fires is long enough (e.g., 20 years) to allow the fir to establish crown dominance *(13,21,40).* Pure stands of white fir frequently begin this way.

White fir is represented in at least 14 forest cover types of western North America. Pure stands are White Fir (Society of American Foresters Type 211) *(19).* It is a major component in Sierra Nevada Mixed Conifer (Type 243) and is also found in the following types:

206	Engelmann Spruce-Subalpine Fir
207	Red Fir
210	Interior Douglas-fir
216	Blue Spruce
217	Aspen
229	Pacific Douglas-fir
231	Port Orford-cedar
237	Interior Ponderosa Pine
244	Pacific Ponderosa Pine-Douglas-fir
245	Pacific Ponderosa Pine
247	Jeffrey Pine
256	California Mixed Subalpine

Life History

Reproduction and Early Growth

Flowering and Fruiting-White fir is monoecious. The reddish male strobili (cones) are generally less than 1.6 cm (0.6 in) long and are densely grouped on the underside of l-year-old twigs about midcrown. Female cones are borne erect on 1-year-old branches, usually in the uppermost crown although both male and female cones are occasionally found on the same branch. California white fir flowers in May or June and fertilization occurs shortly thereafter. Flowering of Rocky Mountain white fir at the higher elevations may be delayed and extend into July. Female cones reach full size, 7.5 to 13 cm (3 to 5 in) long, in late summer and turn from greenish or purplish to brown when mature *(21,521.* Cone specific gravity is about 0.85 when mature (52). The seed matures in September, up to 3 weeks before seeclfall (44).

Seed Production and Dissemination-Studies of white fir seed and cone production in Oregon, California, and the Rocky Mountains indicate that heavy crops are borne on a 3- to 9-year cycle *(25,29,37).* Adequate to good crops are produced more often, generally every 2 to 5 years. On extreme sites, cone production patterns may be different.

Seed size varies widely and a kilogram may contain between 18,960 and 39,070 seeds (8,600 to 17,700/lb) *(50).* Relatively small proportions (20 to 50 percent) of white fir seed are sound, even in good seed years *(21,52).* Seed numbers, however, can reach 1.5 million/ha (600,000/acre) or more *(24,30).* Seed production varies with tree age, size, and dominance. The best, most reliable producers are mature, healthy dominants in the 30- to 89-cm (12- to 35-in) d.b.h. range *(29).* White fir trees can begin bearing cones when only 40 years old and continue beyond 300 years (45). Immature trees can produce heavy seed crops, but their performance is more erratic than that of mature trees *(28).*

Because cones are borne almost exclusively in the uppermost part of the crown, any top damage caused by insects, diseases, or mechanical agents (for example, wind and snow) directly reduces cone production. Large old trees are prone to such damage. Trees that have lost their tops, however, can frequently develop new terminals and resume cone bearing.

Studies in California indicate that mature dominants along the edge of a clearcutting produce between 1.5 and 6.7 times as many cones as similar trees in adjacent closed stands (28). Regeneration data, also from California, indicate that mature trees left in seed tree or shelterwood cuts increase seed production *(42).*

Seeds are released as cones disintegrate on the tree. The white fir seed has a relatively short, broad wing for its weight and falls more rapidly than a pine or spruce seed. Because most dissemination is by wind, the distance of seed spread is more limited than that of many associated species. Reliable

downwind seed spread into an opening generally is limited to 1.5 to 2 times tree height (28).

Seedling Development-White fir seeds germinate in the spring immediately following snowmelt (37) or, where snowpacks are deep, in, on, and under the snow (23). In the Rocky Mountains, white fir germination in spring is in contrast to that of other major species in the mixed conifer type that do not germinate until the summer wet season (37). Seeds that germinate several centimeters above ground in the snowpack rarely survive after snow-melt. Seeds that fall before permanent winter snow cover, therefore, are more likely to produce seedlings. Germination and early growth are best on bare mineral soil. Root systems developed in mineral soil without organic layers are longer, heavier, and have more mycorrhizal root tips than those grown in soil with organic layers *(6)*. White fir seedlings are epigeal.

In general, white fir becomes established best in partial shade, but once established grows best in full sunlight. It is less tolerant of shade than associated true firs (except red fir), is slightly more tolerant than Douglas-fir, and is much more tolerant than pines or oaks *(37,41,56)*. Because white fir can survive and grow beneath heavy brush cover and eventually overtop the brush and dominate the site, many pure stands exist in otherwise mixed conifer areas *(36)*.

Previously it was thought that white fir growth was extremely slow for the first 30 years. It appears now, however, that slow growth beyond 5 years is not inherent and may be caused by environmental conditions, such as prolonged shading and browse or frost damage. White fir is more susceptible to spring frost damage and deer browse than many associated species *(37,41)*.

Radial growth begins before height growth and lasts longer. Height growth begins later in white fir than in associated species at mid-elevations and lasts only about 6 weeks. Occasionally, in California, height growth begins again in late summer. The resulting succulent growth is subject to frost kill. White fir trees from low-elevation seed sources are twice as likely to increase height growth in response to moisture supplied during the summer than are white fir from high elevations or red fir from any elevation (33).

Vegetable Reproduction-White fir shows no tendency to reproduce by sprouting or layering, but cuttings can be rooted with or without hormones. The relative ease with which cuttings from juvenile material can be rooted provides an opportunity to produce genetically selected planting stock at relatively low cost.

Table l-Volume in white fir stands in California and eastern Oregon and Washington at age 100 *(11,53,59)*

Site index[1] and location	Basal area		Volume	
27.4 *m or 90 ft*	***d/ha***	***ft²/acre***	***m³/ha***	***ft³/acre***
California	108	471	1,372	19,600
Oregon and Washington	80	349	1,066	15,230
18.3 *m or 60 ft*				
California	91	397	**805**	11,500
Oregon and Washington	67	291	**633**	**9,039**

[1] Average height of dominant trees at base age 50 years.

Sapling and Pole Stages to Maturity

Growth and Yield-The capacity of white fir to produce large volumes per unit area was recognized before the species was considered of commercial value. As recently as 1962, white fir was regarded as undesirable in forests managed for timber. The productivity of fully stocked, loo-year-old stands in California *(53,59)* and eastern Washington and Oregon *(11)* on good [Site Index 27 m (90 ft)] and average [Site Index 18 m (60 ft)] sites is evident (table 1). The unusual productivity is possible, at least in part, because this species can grow in stands of high basal area. In mixed-conifer stands, white fir still demonstrates a high level of productivity, although its height growth begins to decrease earlier than that of associated species *(10,17)*.

Rooting Habit-Root systems of mature forest trees, including white fir, have not been the subject of much research. What little is known has been gleaned from observations of windthrown trees. Mature white fir rooting habit appears to be fairly adaptable: deep and intensive where soil conditions permit or shallow and widespread where rocks or seasonal water tables limit effective soil depth. There is no strong tendency to maintain a single deep taproot, although rapid taproot development is critical for survival of new germinants in the dry summer climate.

White fir is susceptible to windthrow following partial cutting, especially when marginal codominant and lower crown classes are left as the residual stand. Root diseases contribute significantly to lack of windfirmness. Root grafting between firs is com-

Figure *3-White fir regeneration in a 20-year-old strip clearcut* at *1890 m (6,200 ft) in the southern Cascades.*

mon and is frequently demonstrated by living stumps *(21).* Root grafting is also a factor in the spread of root rots.

Effects of mycorrhizal associations are beginning to be explored. Early information indicates that these root and fungi relationships are significant, especially in establishment and early growth on poor sites, and that bare mineral soil promotes the association *(6).*

Reaction to Competition-White fir has several features of major silvicultural significance. The species is classified as shade tolerant, more so than most of its mixed conifer associates *(41).* Relative shade tolerances of red fir and white fir in the high-elevation transition zone are uncertain. In the northern end of their respective ranges, shade tolerance may be affected by the evident exchange of genetic material with associated species-white fir with grand fir *(A. grandis)* and red fir with noble fir *(A. procera) (2).* White fir is capable of rapid growth to a large size and grows best in full sunlight. It can survive for exceptionally long periods as a suppressed tree and still respond to release by increasing growth dramatically. The time period before growth begins to accelerate varies depending on crown condition at time of release (36). Seed production increases following release even on dominant trees (38).

Because of these features, white fir is a major management consideration in any mixed conifer stand where it is a component. Partial cutting and most shelter-wood cuttings favor white fir and increase its importance in the stand. Prescribed burning in areas where white fir is not desired may be the only reasonable way to control its abundance. Underburning in groves of giant sequoia to control young white firs and to create seedbeds for giant sequoia reproduction is a special example.

To manage pure stands of white fir is relatively easy and, with intensive management, young stands can be extremely productive. White fir can be regenerated naturally or artificially. Natural regeneration can be achieved through clearcutting as long as the maximum downwind width of openings does not exceed 1.5 to 2 times the height of trees left as seed sources (fig. 3). Shelterwood cuttings have been successful in establishing natural regeneration *(30).* On sites where brush competition is a problem, planting under shelterwood has promise. Because of high growth rates in dense, even-aged stands, even-aged management is the likely choice. Uneven-aged management is theoretically possible, however, because of the species' shade tolerance and response to release. The long period of extremely slow growth

under shade and the incidence of dwarf mistletoe infestation make uneven-aged management questionable, however.

Damaging Agents-White fir saplings and poles are susceptible to fire damage or kill, but trees become more resistant to both with age and size. White fir is considered more fire resistant than its associated species at high elevations *(37,41)*, but less resistant than its associates at low elevations (47). Fire scars, commonly found in old-growth stands, provide an entry court for a variety of disease and decay organisms.

White fir is sensitive to spring and fall frosts. Spring frosts can kill developing buds as well as foliage. Damage to established trees, other than Christmas trees, is not usually significant. On some sites, repeated damage to new fir growth can give a competitive advantage to more resistant species. Cold damage to mature trees takes the form of frost cracks and ring shake. Frost cracks are associated with some rot and decay loss (9).

Sudden rises in temperature during May and early June can cause damage nearly identical to that of spring frosts. Sun-scalding following thinning is rare in mature trees, although young, thin-barked trees are susceptible. When white fir boles are injured, recovery is slow (9).

Compared to its associated species, white fir is moderately susceptible to ozone damage. Although fir grows faster than associated species in southern California, diameter growth is affected by oxidant damage as much as that of Ponderosa pine (43). White fir is more resistant to fluoride damage than Douglas-fir or ponderosa pine (37).

As intensive management of this productive species increases, so will the importance of mechanical injury. Studies in Oregon and California have shown that conventional logging techniques for thinning or partial cutting damaged 22 to 50 percent of the residual stand. Seventy-five percent of these wounds were at ground level, where infection by some decay-causing fungus is almost certain (3). Loss of volume by time of final harvest can be considerable.

Two parasitic plants, white fir mistletoe ***(Phoradendron bolleanum*** subsp. *pauciflorum), a* true mistletoe, and white fir dwarf mistletoe ***(Arceuthobium abietinum*** f. sp. ***concoloris),*** cause major damage to white fir (9). In Arizona, Mexico, and the central to southern Sierra Nevada of California, white fir mistletoe is a serious problem on large old trees. Heavy infections cause spike tops, loss of vigor, and increased susceptibility to bark beetle attack. Dwarf mistletoe is a major problem from the southern Sierra Nevada north into Oregon. It is found elsewhere throughout the native range of white fir in coastal and southern California, Nevada, and Arizona *(39,63)*.

One-third of the white fir stands in California are severely infested by dwarf mistletoe and the parasite is present in other forest types that contain white fir. Heavily infected trees suffer significant growth losses and are prone to attack by ***Cytospora abietis,*** a fungus that kills branches and further reduces growth. Because of reduced vigor, infected trees are more susceptible to bark beetle attack and various diseases *(50,51)*. Heart rots, entering through open mistletoe stem cankers, increase mortality of old-growth trees through stem breakage.

Changes in wood structure in the large stem bulges caused by dwarf mistletoe infections reduce the strength of lumber produced. Current lumber grading practices, however, are not adequate to identify the affected wood (61).

Dwarf mistletoe need not be a problem in young managed stands because three factors make damage subject to silvicultural control. The parasite is host specific: white fir can be infected only by ***A. abietinum*** f. sp. ***concoloris,*** which in turn can parasitize only one other fir, grand fir. Small trees (less than 1 m 13.3 ftl tall) are essentially free from infection even in infested stands. Infected young firs free from new overstory infection outgrow the spread of mistletoe if height growth is at least 0.3 m (1 ft) per year (50).

Annosus root rot ***(Heterobasidion annosum)*** is present in all conifer stands and may become a major disease problem as management of white fir increases. Once established, the disease affects trees within a slowly expanding, circular infection center. Spread from tree to tree is through root contacts. New infection centers begin by aerial spread of spores and infection of basal wounds and freshly cut stumps. In true fir, annosus root rot usually does not kill directly but produces considerable moisture stress and loss of vigor that predispose the tree to attack by bark beetles, notably *Scolytus*. Direct damage resulting from infection is restricted primarily to heart rot of butt and major roots, leading to windthrow and stem breakage (9). Some degree of control is available through silvicultural means and use of borax on freshly cut stumps.

Other rots of major significance include the yellow cap fungus ***(Pholiota limonella),*** Indian paint fungus ***(Echindontium tinctorium),*** and white pocket rot ***(Phellinus pini) (9).*** Yellow cap fungus causes heavy losses from butt rot and enters through fire scars and basal wounds (9). Indian paint fungus is a major heart rot organism. This fungus probably infects fir

in the same manner it does western hemlock (3). Entry is through branchlets less than 2 mm (0.08 in) in diameter. The fungus can remain dormant for up to 50 years before being activated by injury to the tree *(18)*. Rot commonly extends 3 m (11 ft) below and 6 m (20 ft) above each characteristic fruiting body (4). No effective control is known although trees less than *40* years old are relatively free of rot because they have so little heartwood. In the white fir-grand fir complex of Idaho, the fungus was found in 97 percent of the trees that had decay. Almost 80 percent of the decay in old-growth grand fir-white fir stands of eastern Oregon and Washington is caused by Indian paint fungus; in California, it is much less common (9).

Insects from seven genera attack white fir cones and seeds. Two cause damage with considerable loss of seed. Seed maggots *(Earomyia* spp.) are the most abundant and damaging. The fir cone looper *(Eupithecia spermaphaga)* covers almost the entire range of white fir and periodically causes considerable local damage (27).

Although many insects feed on white fir foliage, few cause significant damage as defoliators. The most destructive of these is the Douglas-fir tussock moth *(Orgyia pseudotsugata)*. Over most of its range the tussock moth shows equal preference for true fir and Douglas-fir foliage. Epidemic outbreaks, although sporadic, are explosive and damaging. In California, white fir is the preferred host, but outbreaks have not reached the severe levels sustained elsewhere (27). Occasionally, localized outbreaks result in increased stand growth as mortality of subordinate trees "thin" an overdense stand *(59,60)*.

The western spruce budworm *(Choristoneura occidentalis)* is the most destructive defoliator in western North America, causing serious damage in Canada and the Rocky Mountains and Pacific coast regions of the United States. Some outbreaks are short lived, but some continue for 20 years or more. Although initial damage is to new foliage and buds, trees can be completely defoliated in 4 to 5 years. Ultimate damage ranges from minor growth loss to major tree mortality over extensive areas, depending on severity and duration of the outbreak (27).

A similar species, the Modoc budworm *(Choristeneuru retiniana* [= *viridis*]), is endemic to the Warner Mountains of northeastern California and southeastern Oregon. Damage to California white fir in the Warner Range has been sporadic and light *(27)*.

The New Mexico fir looper *(Galenara consimilis)* is restricted to New Mexico and can be a serious problem locally on white fir. Weevils of the genus *Agronus* attack foliage of young trees and may cause concern with intensive forest management. Sawflies *(Neodiprion* spp.) are generally not a problem-but are potentially damaging in dense stands of young fir. In California, a species of *Neodiprion* sawfly has reached epidemic levels locally on white fir. White fir needleminer *(Epinotia meritana)* covers the full range of white fir and can cause extensive branch kill predisposing trees to bark beetle *(Scolytus)* attack (27).

Cutworms *(Noctuidae)* can be a problem in nurseries and, more especially, in natural regeneration areas. Cutworms have been responsible for more than 30 percent of the seedling mortality in California *(21,28)*.

The most damaging white fir pest is the fir engraver beetle *(Scolytus ventralis)*. This bark beetle is found over the entire range of white fir and causes serious damage nearly everywhere. Mortality equivalent to an estimated 2.4 million m^3 (430 million fbm) of growing stock is caused each year in California alone. Losses during epidemics are even larger (27). The fir engraver can attack any tree, but those suffering from root rot infections or tussock moth attack are especially vulnerable. In general, anything that reduces tree vigor, such as mistletoes, *Cytosporu,* drought, or fire, increases susceptibility to attack (20). Several other bark beetles-including one species of *Pseudohylesinus* and two species of *Scolytus,* the roundheaded borer *(Tetropium abietis)* and the flatheaded fir borer *(Melanophila drummondi)*—frequently join the fir engraver in attacking and killing individual trees. In epidemic conditions, however, mortality is primarily caused by the fir engraver. Maintenance of stand health and vigor is the only known control (27).

Locally, small rodents can cause significant loss of seed and occasionally girdle seedlings. Pocket gophers limit regeneration in many areas, particularly clear-cuts, by feeding on fir seedlings during winter and spring. Pocket gophers in combination with meadow voles and heavy brush can prevent conifer establishment for decades *(21,37)*. Pocket gopher damage occurs on trees of all ages and sizes. Feeding on root tissues at the root crown has girdled saplings up to 12.7 cm (5 in) in diameter at breast height (d.b.h.). In at least one place, such feeding has resulted in death of mature trees up to 93.7 cm (36.9 in) d.b.h. (32). Direct control of pocket gopher is difficult and expensive. Indirect control by habitat manipulation offers some possibilities.

Spring browsing of succulent growth by deer and other big game animals can retard height growth for many years. Normally, trees are not killed, and most can grow rapidly once browsing pressure is removed. In managed stands, however, reduced height growth

can result in significant economic loss. Damage by big game can be severe in the Southwest. Damage from livestock grazing is limited primarily to trampling and appears to be decreasing as the number of cattle on the open range decreases (37).

Special Uses

White fir is a general, all-purpose, construction-grade wood used extensively for solid construction framing and plywood. A significant portion of the Christmas trees used in California are young white fir. These trees are harvested from natural stands, from regeneration areas where the trees are cultured for as long as 11 years before harvest, and from areas used specifically for Christmas tree production.

Detailed and exact wildlife censuses for large areas do not exist, and any listing of species numbers associated with a major forest type is an approximation. There are, however, about 123 species of birds found in the white fir type of California, 50 of which are associated primarily with mature forests. Perhaps because of the dense nature of most true fir forests in California, there are only 33 species of mammals commonly present and of these only 7 are generally associated with mature forests. Reptiles are represented by 17 species, mostly at lower elevations. Only eight are regularly associated with mature forests (58).

Genetics

White fir is an adaptable and genetically plastic species. Throughout its range, elevational and latitudinal gradients are reflected as changes in stomata1 number and arrangement, needle shape, growth rate, phenology, *(34),* and trachied length *(16).*

Interspecific crossbreeding is reasonably easy between fir species within the same group (e.g., ***A. concolor*** and ***A. grandis*** within Section ***Grczndes),*** but difficult to impossible between sections *(15,35,55).* In the northern portion of its range, California white fir inter-grades and hybridizes freely with grand fir, both being in the Section or group Grandes ***(15).*** The species are morphologically, ecologically, and chemically distinct *(20,31).* They differ in stomata1 number and reaction to moisture stress (63). Grand fir grows most abundantly on cool, moist sites and white fir on warmer, drier sites. Grand fir has a higher incidence of heart rot than white fir. Grand fir bark has a red-purple periderm and is high in camphene. White fir bark periderm is yellowish and camphene content is low *(62).* Hybrid trees are intermediate in all of these characteristics, including incidence of heart rot, which may be more closely related to cool, wet sites than to genetic differences (26).

Over a large area from northwestern California through central Oregon and into central Idaho, identification of the two species is difficult and sometimes impossible. White fir in this region is called "grandicolor."

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