Pinus radiata D. Don Monterey Pine

Pinaceae Pine family

Philip M. McDonald and Robert J. Laacke

Monterey pine *(Pinus rudiatu)* is the most widely planted pine in the world (9). Rapid growth and desirable lumber and pulp qualities cause it to be the leading introduced species in Australia, New Zealand, and Spain *(34)*, and a major species in plantations of Argentina, Chile, Uruguay, Kenya, and the Republic of South Africa. In these countries, Monterey pine is a mainstay of the forest economy, serving internal markets, generating valuable foreign exchange reserves as an export, and reducing cutting pressure on native forests.

Pinus rudiatu was first noted by Thomas Coulter at Monterey, CA, in 1830. The scientific name refers to the strong markings on the cone scales, and the common name to the peninsula on which it grows extensively. Other common names are insignis pine and radiata pine. Radiata pine is a common name increasingly used worldwide; pino insigne is the Spanish equivalent.

Habitat

Native Range

Native stands of Monterey pine (fig.1) are found in three distinct areas of central-coastal California in San Mateo, Santa Cruz, Monterey, and San Luis Obispo Counties. The northernmost stand is east of point Año Nuevo, the central stand 48 km (30 mi) to the south near Monterey and Carmel, and the southernmost stand about 105 km (65 mi) away in the Pico Creek-Cambria area *(15)*. Seldom is the pine found more than 11 km (7 mi) from the sea. The north-south range is about 209 km (130 mi). A close relative of Monterey pine also inhabits the northeastern portion of Guadalupe Island and the northern and central parts of Cedros Island-both of which are Mexican possessions. Guadalupe Island is 740 km (460 mi) south of Cambria, and Cedros Island is 908 km (564 mi) south-southeast of Cambria. Although trees on these islands differ in morphology from those in the United States, they have now been shown to be most closely related to *P. radiata (21)*.

The area occupied by natural stands of Monterey pine on the United States mainland was once well defined, even though estimates of the total area ranged from 4860 to 6480 ha (12,000 to 16,000 acres) (28). Precise natural limits, however, are now difficult to determine because of conspicuous amounts of new regeneration. The southern part of the forest at Año Nuevo, for example, is estimated to have in-

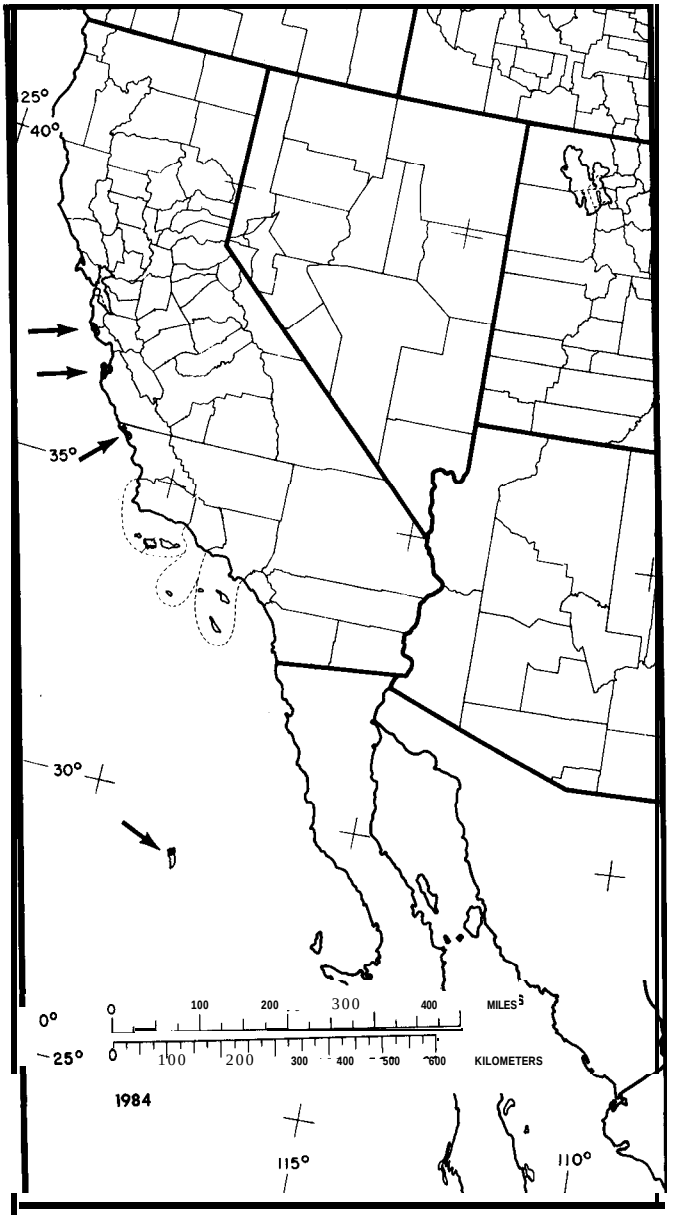

Figure l--The *native range of Monterey pine.*

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creased by as much as 95 ha (235 acres) in recent decades (14). Additional trees have been planted, and these also have produced seed that led to many acres of new reproduction. Nevertheless, the total area currently occupied probably is no more than 8000 ha (19,770 acres) (21).

Climate

The Monterey pine habitat is strongly influenced by its proximity to the Pacific Ocean from which the cold waters of southward-flowing currents result in high humidity, low temperatures, and summer fogs. The minimum relative humidity at Monterey in July, for example, averages between 60 and 70 percent (23). At least one-third of the days each year are foggy (35).

Temperatures tend to be mild, although extremes range from about –5° to 41° C (23" to 106" F). Mean monthly temperatures show a relatively even climate with a difference between the coldest and warmest month of about 6.5" C (12" F) in the range of 9" to 11" C (48" to 52" F) in winter and 16" to 18" C (61° to 64" F) in summer. Mean temperatures during the growing season, February through June, range from 11° to 16° C (52" to 61" F), with maximums of 17" to 24° C (63" to 75" F) (34). Frost-free days number about 300 each year.

Annual precipitation ranges from about 380 to 890 mm (15 to 35 in) and varies from year to year. From December to March, precipitation averages 300 to 510 mm (12 to 20 in), with less than 50 mm (2 in) per month for the remaining months. Rain usually does not fall in July and August. During these months, however, the tree crowns collect moisture from fog that moves inland. Fog drip can amount to as much as 15 mm (0.59 in) per week at higher elevations on the Monterey Peninsula (25). No snow falls in the natural range of Monterey pine. Año Nuevo is the wettest of the three mainland locales; Cambria, the driest; and Monterey, the foggiest (3).

Wind is, at best, a minor climatic influence, averaging only 7.6 km/b (4.7 mi/h) on an annual basis. May is the windiest month, August the least windy (23).

The climate of Guadalupe and Cedros Islands is Mediterranean-like, possibly with less rainfall and greater temperature extremes than for mainland stands. Fog is a critical factor and, on both islands, pine stands are restricted to foggy ridges and windward slopes, or occasionally to the moist slopes of deep canyons. On Cedros Island, fog was most frequent and of maximum concentration where the pines grew, and each pine grove tended to be covered with fog while the desert between was exposed to clear sky (22).

Soils and Topography

In spite of a small and narrow natural range, Monterey pine grows on soils that are derived from a variety of parent materials. At Año Nuevo, for example, the underlying rocks are shales and marine sandstones. At Monterey, these rocks and granite are present, and at Cambria, parent materials are limestones, sandstones, cherts, and slates.

Monterey pine is found on soils of four orders. Mollisols are the most prominent and include four Haploxerolls (Santa Lucia, Ben Lomond, Catelli, and Baywood soil series) (36) and four Argialbolls (San Simeon, Conception, Watsonville, and Chamise series). Ultisols are next in extent and are represented by an Albaqualt (Narlon series). The Entisol order is represented by one soil series, a Xeropsamment (Tangair series), and the Alfisol order by a Palexeralf (Tierra series).

At all three locations—Año Nuevo, Monterey, and Cambria-the soils have a number of similarities. Most soils are deep sandy loams, often derived from marine sediments. A thick accumulation of organic material is common beneath Monterey pine stands on good sites. The 8- to 15-cm (3- to 6-in) layer of organic material stores many times its weight in water and is a modest reservoir for nutrients. Most soils are found on sloping ground and are reasonably well drained, at least down to a clay layer at the 50- to 85-cm (20- to 33-in) depth. The clay layer is of critical importance. Pine roots generally do not extend far into this layer, but many penetrate for a short distance. Such roots have been observed to be well inoculated with mycorrhizae (10). Another common attribute of soils supporting Monterey pine is that soil pH generally is acid, even extremely acid. Acidity often is high at or just above the clay layer. The combination of poor drainage and high acidity seems to enhance mycorrhizal formation. The clay layer, then, intercepts winter rains and forms a reservoir of water that is available for most of the year. Mycorrhizae on roots at or in the clay layer enhance the nutrient- and water-gathering capability of the pines. Of the seven most common mycorrhizal species that colonize the roots of Monterey pine seedlings in nurseries, ***Rhizopogon rubescens*** and ***R. luteolus*** enhanced height growth and nutrient uptake the most (6).

In general, the topography on which Monterey pine grows is hilly and gently to moderately sloping. With one possible exception in the Santa Lucia Mountains, elevations range from sea level to about 305 m (1,000

ft). At the three mainland elevations, the most extensive stands are found on modest slopes or gently rolling terrain between the ocean and steeper inland hills. The pine is found on north aspects at all locations and shifts from all aspects at Año Nuevo, through presence only in sheltered canyons on south aspects at Monterey, to complete absence on all other aspects at Cambria. On Guadalupe and Cedros Islands, stands are found on gentle to steep slopes at elevational ranges of 300 to 1100 m (980 to 3,610 ft) on Guadalupe, and 275 to 640 m (900 to 2,100 ft) on Cedros ***(21).***

Limitations in habitat at each location probably contribute to the area1 extent of the Monterey pine stands. At Año Nuevo, shallow soil near the coast could be limiting. At Monterey, lower rainfall together with differences in soil depth, texture, and location of clay layer could govern distribution. At Cambria, climate and soil mandate a shift from trees to grass and shrubs. Among the three mainland areas, where genetically controlled differences in tolerance to cold have been noted, the tolerance decreases from north to south ***(16).*** Recently, analyses of satellite photos taken over several years have shown that the present groves of closed-cone pines "are all at centers of high fog concentrations" (3). For the three mainland areas, the factor limiting the natural range of Monterey pine at its eastern boundary could be fog, but fog does not sufficiently explain the abrupt northern and southern termination of the pines' natural range. Farther south on Guadalupe and Cedros Islands, absence of fog appears to limit the distribution of the species. In spite of these evident limitations, the causes of restrictions on the range of Monterey pine are not clear.

Associated Forest Cover

Monterey pine has been listed in at least two vegetation classifications: the Closed-Cone Pine Forest Community of California (27) and the Closed-Cone Pine and Cypress Californian Floristic Province *(31).*

The fossil record, although somewhat limited, indicates that this pine once occupied a larger range during the late Pleistocene epoch, extending almost continuously along the outer coastal strip and California islands. Fossil remains have been found at Tomales Bay, Little Sur, Carpinteria, Rancho La Brea, and Santa Cruz Island. The evidence suggests that present-day pines are survivors of an ancient oak-laurel, pine, and palm forest that grew well in a mild climate (2).

Fire is a major influence affecting the extent and makeup of Monterey pine stands. Fire is frequent, sometimes of natural causes, often accidental, and sometimes deliberately set. Graziers at Cambria, for example, burned the woods to obtain more grass. At Año Nuevo, frequent fires have helped to maintain the pine forest. Without fire, the taller and longer-lived coast Douglas-fir ***(Pseudotsuga menziesii*** var. ***menziesii)*** would usurp land occupied by pines. Much regeneration and a number of even-aged stands at all three mainland locations can be traced directly to the influence of fire.

Many of the plant species associated with Monterey pine have been listed (32). Such lists are subject to change because undisturbed stands are scarce; nearly all have been grazed, burned, or logged.

At Año Nuevo, tree associates of Monterey pine are coast Douglas-fir, redwood ***(Sequoia sempervirens),*** knobcone pine *(Pinus* ***attenuata),*** ponderosa pine *(P.* ***ponderosa*** var. ***ponderosa),*** coast live oak ***(Quercus agrifolia),*** and Pacific madrone ***(Arbutus menziesii).*** Some portions of the Monterey pine forest are pure and almost fully stocked with 370 to 740 trees per hectare (150 to 300/acre). Width of tree crowns varies with age, but rarely are crowns interlocking. Monterey pine also intermingles with Douglas-fir on middle slopes and with knobcone pine and an oc-

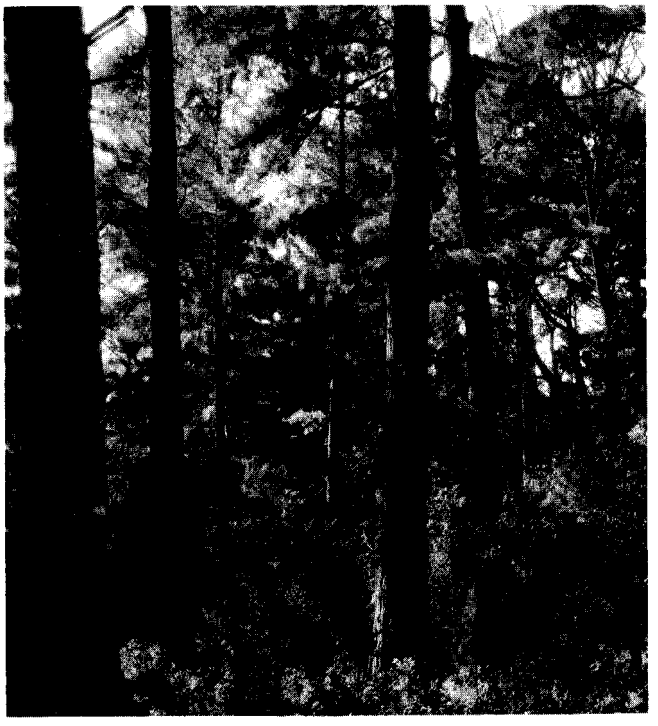

Figure 2—*An open mature stand of Monterey pine in the Año Nuevo Creek drainage with a poison-oak, California buckthorn, and California blackberry understory.*

casional ponderosa pine on upper drier slopes, especially where the soil is shallow and rocky. On lower slopes, redwood and an occasional madrone are present. Coast live oak, usually in the understory, also is an associate species. In some places, natural regeneration of Monterey pine is prominent, particularly where disturbance has bared the soil.

Understory associates generally are not particularly diverse nor abundant at Año Nuevo. In places, however, understory vegetation fully occupies the ground (fig. 2). In addition to young coast live oak, the most common species are bracken ***(Pteridium aquilinum),*** poison-oak ***(Toxicodendron diversilobum),*** coyotebrush *(Baccharis pilularis)*, blueblossom ***(Ceanothus thyrsiflorus)***, California buckthorn ***(Rhamnus californica),*** blackberry *(Rubus* spp.), coast sagebrush *(Artemisia* ***californica),*** and several grasses.

At Monterey, tree associates are coast live oak, Monterey cypress ***(Cupressus macrocarpa),*** Gowen cypress *(C.* ***goveniana),*** and bishop pine *(Pinus muricata)*. Coast live oak is the most common tree associate of Monterey pine. Seldom taller than 9 m (30 ft), the oak usually is relegated to the understory. White alder *(Alnus rhombifolia)* and a species of willow *(Salix* sp.) are occasional associates in riparian zones. At least one species of willow is scattered throughout the forest on higher ground.

Shrubs and forbs in the Monterey forest vary with time after disturbance and general quality of the habitat. Successionally, young stands of pines, shrubs, and forbs often become established after fire.

Figure *3-Monterey pine on the grassy edge of its natural range near Cambria.*

At age 45, Monterey pine has a stand density of 160 to 200 trees per hectare (65 to 81/acre). Shaggy-bark manzanita ***(Arctostaphylos tomentosa)*** and California huckleberry *(Vaccinium ovatum)* are prominent with an average cover of about 50 percent. By the time Monterey pine reaches age 65, competition, disease, and slow growth reduce its density to 80 to 120 trees per hectare (32 to 49/acre). In stands of this age, poison-oak, bush monkeyflower *(Mimulus* ***aurantiacus)*** and California blackberry ***(Rubus ursinus)*** are present and, along with the shrubs mentioned earlier, contribute to a shrub cover of about 40 percent. Openings form in the pine stand as the trees grow older but density remains about as before because younger age classes of pines contribute. Shrub cover continues at about 40 percent with poison-oak and creeping snowberry *(Symphoricarpos mollis)* becoming the understory dominants. In old stands where tree diameters are over 100 cm (39 in), one or more age classes of pine are present. Coast live oak sometimes constitutes 25 to 50 percent of the trees in such stands (37).

At Cambria, tree associates of Monterey pine are limited to one hardwood: coast live oak. On better sites, understory vegetation near the typically open pine stands includes coast live oak, bracken, California blackberry, and poison-oak. On drier sites, coast sagebrush, coyotebrush, and bush monkeyflower are present. At the edge of the pine's natural range, grasses often are the only understory plants (fig. 3).

On Guadalupe and Cedros Islands, vegetation associated with Monterey pine is poorly known. That reported for Guadalupe Island is island live oak *(Quercus tomentella)*, Guadalupe Island palm ***(Erythea edulis)***, and grasses; for Cedros, bishop pine, yucca (Yucca spp.), and at least two species of cactus *(Opuntia* spp.).

Life History

Reproduction and Early Growth

Flowering and Fruiting-In its native habitat, Monterey pine "flowers" in late winter and early spring. The species is monoecious; the numerous yellow male strobili are produced on side branches, and female flowers are produced in all parts of the crown. Monterey pine is multinodal and female strobili occasionally are found at a secondary whorl position *(18)*.

Seed Production and Dissemination-Fertile cones are produced as early as 5 to 10 years, but substantial crops are not yielded until age 15 or 20 if the trees are open-grown, and considerably later if

the stands are dense. Cones mature in the autumn of the second season and most open during the first warm days of late winter and. early spring. They range in color from lustrous nut brown to light brown when ripe, and in length from 8 to 18 cm (3 to 7 in). The ellipsoid seeds, jet black and pimpled, average about 2 cm (0.8 in) long. Monterey pines at Cambria have the largest cones and seeds; those at Monterey the smallest *(11)*. Each cone contains from 120 to 200 seeds.

Cones remain attached to the trees for many years and open and close several times, depending on temperature and humidity. Because the habitat of the species is typically cool and moist, cone opening is infrequent and of short duration, so that seeds are often retained and then disseminated over a longer period than in warmer and drier climates.

Although cones and seeds are produced almost every year, seedfall varies. A relatively small number of seeds dribble out of the cones each year. In warm and dry years, seedfall can be heavy. Fire is particularly effective for opening cones and releasing large quantities of stored seeds.

Several species of birds and small mammals depend in part for sustenance on the seeds of Monterey pine. Principal bird species are the scrub jay, Stellar jay, and common crow. Important small mammals are deer mice, chipmunks, and ground squirrels (7). Numerous other creatures eat the seeds of this pine, but their effect usually is insignificant.

Seedling Development-Although the seeds of Monterey pine do not require stratification for good performance, germination is enhanced by it. Cold-moist stratification of 0 to 7 days is recommended for fresh seed and 7 to 20 days for stored seed. In one test with no pretreatment of seed, germinative energy was 16 percent in 7 days and germinative capacity 81 percent after 25 days at a controlled temperature of 20" C (68" F). In another test, again with no pretreatment, but where the day temperature was held at 30" C (86" F) and the night temperature at 20" C (68" F), germinative capacity was 67 percent after 28 days *(18)*.

Germination is epigeal. New germinants bear a whorl of five to nine cotyledons that are succeeded by primary needles. Secondary needles in fascicle bundles form when the seedling is a few months old, After age 3, the seedling produces only secondary needles. The root system of most seedlings consists of a slender taproot, aimed straight down.

Mycorrhizal associations with root tips in the upper 10 cm (4 in) of soil probably increase nutrient and water intake and enhance the growth of Monterey pine seedlings. At least 16 mycorrhizal fungi associated with Monterey pine have been identified in the United States and several others noted in other countries (28).

The seedbed required for natural regeneration of Monterey pine is highly variable. The best seedbed is moist mineral soil free of competing vegetation. Numerous seedlings, however, are found where the seedbed consists of several inches of pine needles over mineral soil (23). Although unknown, these seedlings could be the survivors of a great many seedlings and they could be much older than similar-sized, free-to-grow counterparts on bare mineral soil.

Seedlings develop best in full sunlight. Soil disturbed by logging and fire is conducive to seedling establishment and rapid growth. Dense slash decreases seedling density, although light slash can improve the seedling "catch."

Optimum conditions for regeneration, however, are produced by fire; maximum numbers of cones are opened, and at least a temporarily competition-free and receptive seedbed is prepared (37). As a result, dense stands often are formed after burning. In fire-killed stands in foreign countries, Monterey pine seedlings were reported to number 1,235,500/ha (500,000/acre) and more than 2,471,000/ha (1,000,000/acre) (32).

On Guadalupe Island, seedlings and saplings are scarce. "Very dense reproduction," however, was recorded in places on Cedros Island (21).

Pines also become established in grassland vegetation and beneath live oaks, the latter providing shade during the critical establishment period. In most instances, the pines eventually grow through the oak canopy and dominate (23). Some pines reproduce naturally under the canopies of older trees. Number and vigor of pine seedlings and saplings relate directly to the spacing of the older trees; the more dense the overstory, the fewer and slower growing the seedlings. Dense thickets often are formed in small openings.

Naturally established Monterey pine seedlings are fairly large initially and grow larger quickly. Seedlings 30 to 56 cm (12 to 22 in) tall after one growing season are common. Rapid shoot growth usually starts in February and continues until September. Monterey pine apparently begins growth at colder soil temperatures than associated conifers. Lack of soil moisture limits growth in the fall. The period of growth is variable, differing from tree to tree and from season to season (23). By age 5, trees are about 6.6 cm (2.6 in) in d.b.h. and 6 m (20 ft) tall *(19)*. By this age, seedling roots have expanded much more laterally than vertically and have formed a lateral, rather than a taproot, system.

Artificial regeneration of Monterey pine in California is usually for horticultural rather than timber-growing purposes; however, several large plantations have been established for a variety of reasons. The most successful and long-lasting plantations are in central California near the Pacific Ocean (28).

Monterey pine grows readily in California nurseries. Its only problem is rapid growth and stock too large for field planting. At one nursery, average seedling height was 41 cm (16 in), accumulating from the normal seeding date in April to lifting in January.

Seedling size and growth are affected by seed size, soil temperature, and soil moisture. After 32 weeks, Monterey pine seedlings were taller and heavier from seeds retained by a 0.39 cm (0.15 in) mesh screen than from seeds passing through a 0.33 cm (0.13 in) screen *(13).*

Seedling root growth was greatest at 15" C (59" F), a value 5" C (9" F) lower than the optimum soil temperature reported for other pines. Monterey pines with a predawn water potential of -1.5 MPa (-15 bars) were unable to open stomates, a phenomenon also noted at a similar value for ponderosa and lodgepole *(Pinus contorta)* pines *(17).*

Vegetative Reproduction-Monterey pine does not reproduce naturally from sprouts, and no record of sprouting in natural stands is known.

Reproduction from artificially rooted propagules of this pine has been successful in many trials in several countries. Hedging is one method for successfully mass-producing large numbers of symmetrical and straight cuttings and maintaining the juvenile nature of propagules (22). Plantlets from embryos and cotyledons are another *(1).*

Cuttings, or other means of vegetative propagation, offer a number of advantages over seedlings, not the least of which is closer control of genotype. Cuttings from mature planting stock show a reduced incidence of retarded leaders, excessive branching, crooked internodes, and frost susceptibility. Vegetative propagules also tend to have straighter boles, less forking, fewer and smaller branches, less bole taper, and thinner bark (22). Height growth of cuttings generally is similar to that of seedlings, although extremes of environment and age of ortet can cause lower growth than from seedlings. Cuttings also develop a higher frequency of cones on the bole-a negative factor. This can be mitigated by pruning, however.

Sapling and Pole Stages to Maturity

Growth and Yield-On good sites, pine saplings that are free to grow and have at least moderate spacing enlarge rapidly: an increase in height of 1.2 to 2.4 m (4 to 8 ft) per year has been observed (23). By age 15, trees are 24 cm (9.4 in) in d.b.h. and 16 m (53 ft) tall *(19).* These values indicate a growth rate for the first 15 years that places Monterey pine among the most rapidly growing of American conifers. Although reproduction can be very dense, stands seldom, if ever, stagnate. A few saplings grow faster than their counterparts, quickly establish dominance, and eventually form the well-spaced, relatively open stands typical of older Monterey pine forests.

Branches of Monterey pine saplings die when shaded but persist on the bole for many years. In dense stands, the trunks clean themselves well *(35).* Mature trees often have clear boles for 8 to 15 m (26 to 49 ft).

Height growth of pole-sized trees on poor sites may slow down appreciably after 15 years, but on better sites, it continues at a good rate until trees are about age 50 *(19).* At Monterey, pole-sized trees less than 30 cm (12 in) in d.b.h. average about 20 years old and 20 m (64 ft) tall. Height of mature trees ranges from 9 to 38 m (30 to 125 ft) but generally is 21 to 30 m (69 to 98 R), with the tallest trees often found in small gullies. Diameters vary widely and, on a good site, average just under 64 cm (25 in) in d.b.h. A few trees reach an exceptional diameter of 122 cm (48 in) in d.b.h. At Cambria, Monterey pines are a little taller, averaging 30 to 37 m (98 to 121 ft) at maturity *(23).*

On Guadalupe Island, the tallest tree was 33 m (108 ft); the largest d.b.h. recorded was 211 cm (83 in). On Cedros Island, the tallest tree measured 32 m (105 ft); the tree with the largest d.b.h. was 77 cm (30 in) *(21).*

Crown development of Monterey pine is a function of age and spacing. In crowded conditions, the species has a narrow pointed crown. Vigorous trees continue to have pointed crowns until 35 to 45 years of age, after which the crown becomes flat and irregular. Trees 30 to 46 cm (12 to 18 in) in d.b.h. have crowns 5 to 6 m (16 to 20 ft) wide, but much narrower if crowded, and those larger than 76 cm (30 in) in d.b.h. have crowns 9 to 12 m (30 to 39 ft) wide. Trees taller than 30 m (98 ft) have a live crown one-third to one-sixth of this length (23).

Monterey pine is short lived. It attains full size in 80 to 100 years and rarely lives beyond 150 years *(35).*

Yield of Monterey pine in natural stands is lowered by the characteristically open spacing of the trees. Pine volume averages less than 281 m^3/ha (4,011 $ft^3/acre$). As stocking increases, so does productivity. A stand with better than average stocking, for ex-

ample, averaged 490 m^3/ha (7,003 ft^3/acre). Trees were about 50 years old, 39 cm (15 in) in d.b.h., and numbered 408/ha (165/acre). The best stocked stand at Monterey contained 482 trees and 1681 m^3/ha (195 trees and 24,009 ft^3/acre). These trees averaged 52 cm (20 in) in d.b.h. and 29 m (95 ft) in height (19).

In other countries, the yield of Monterey pine in plantations that are thinned and pruned and sometimes fertilized is much higher than that of natural stands. In New Zealand, stands 35 to 40 years old yield about 770 m^3/ha (11,004 ft^3/acre). On a productive site in Chile, trees 20 years old produce about 500 m^3/ha (7,145 ft^3/acre). They number about 270 trees per hectare (109/acre) after three thinnings, average about 48 cm (19 in) in d.b.h., and have been pruned three times *(30)*.

Rooting Habit-After age 5, the roots of pine seedlings grow downward as far as soil depth or the clay layer permit. Main support roots, however, develop in the top 61 cm (24 in), even in deeper soils (23). Studies at Monterey and Cambria showed at least a few pine roots penetrated to 1.7 m (5.5 ft) in deeper soils *(8,10)*. The root system becomes extensive laterally and roots of mature pines extend from 9 to 12 m (30 to 39 ft) from the tree (19). Where a layer of organic matter covers the soil, large numbers of small pine roots exploit the layer for moisture and nutrients.

The species is regarded as moderately windfirm on deeper soils but less so on shallow soils. Trees growing in soils saturated with moisture are vulnerable to windthrow, particularly in exposed places (24).

Reaction to Competition-Because Monterey pine exists both as an overstory and an understory tree, it is classed as intermediate in tolerance to shade *(4)*—that is, at least as tolerant as any other pine in western North America. Age and site quality, however, affect this assessment. As a sapling or seedling, the species tolerates shade but becomes less tolerant in the pole stage and is intolerant when mature (19). When overtopped, young pines can withstand a considerable amount of suppression, struggling along for 30 years or more before they die.

Damaging Agents-Within its restricted range, few abiotic factors cause significant damage except pollution, especially ozone. Because of its rapid growth, Monterey pine has been planted widely along the western coast of North America. In these plantings and even in the Central Valley of California, the pine technically is an introduced species because it is exposed to environmental conditions rare in its native range. Temperatures below freezing for only a few hours seriously damage and kill trees of all ages. Trees that are rapidly growing or newly planted are susceptible to windthrow during winter storms. Sudden increases in temperature to 38" C (100° F) or greater cause needle scorch and damage to new growth (5).

Fire is a particular hazard to young, thin-barked trees and can be disastrous in dense plantations where persistent lower limbs become festooned with dead needles, resulting in an ideal situation for crowning fires. Pruning to a height of 2.1 to 2.4 m (7 to 8 ft) helps keep a fire on the ground and is a desirable measure for protection (32).

Pathogens of significance in the natural range of Monterey pine include a dwarf mistletoe, two gall rusts, and two root diseases. Digger pine dwarf mistletoe ***(Arceuthobium occidentale)*** infects trees of all ages and is found in native stands except at Año Nuevo (32). Western gall rust ***(Peridermium harknessii)*** and coastal gall rust ***(P. cerebroides)*** are found in the three stands in the United States and cause significant damage to young trees. Cedros and Guadalupe Island populations of Monterey pine have higher resistance to western gall rust than mainland populations (29). A widespread pathogen of particular virulence is annosus root disease ***(Heterobasidion annosum).*** Armillaria root disease ***(Armillaria mellea)*** is found where oaks are present, but damage to Monterey pine is minor.

Outside its natural range, Monterey pine is attacked by several pathogens in addition to those in native stands. Of these, the red band needle blight *(Scirrhia pini)* is the most damaging. This worldwide pathogen is not found in native stands but has caused serious damage and is a major concern for plantations in British Columbia, Washington, Oregon, and northcoastal California. Western gall rust is a pest in plantations from central California to British Columbia and can be damaging to Christmas tree plantations. As many as 35 other pathogens cause negligible to minor damage in exotic stands of Monterey pine *(5,32)*.

Furniss and Carolin ***(12)*** list 56 insects from 44 genera that feed on Monterey pine foliage, twigs, branches, and boles. Relatively few of these cause significant damage and only five can kill trees, especially those weakened by other agents. Four are bark beetles and one is a weevil; all are cambium feeders.

Bark beetle larvae mine the cambium of all but young trees. Once the trunk is girdled, the tree dies. All four species produce broods in stumps or fresh cut limbs and logs and commonly work in concert on individual trees. The Monterey pine ips *(Ips mexicanus)* is seldom a primary killer except in young plantations. The California four-spined ips ***(I.***

plastographus) and pinyon ips *(I. confusus)* attack large and small trees. The red turpentine beetle *(Dendroctonus valens)* kills large, mature trees.

The Monterey pine weevil *(Pissodes radiatae)* is primarily a threat to young trees where the larvae mine cambium in tops, stems, bases, and even portions below ground.

Various other insects, including aphids, borers, caterpillars, and moths, cause minor damage. Probably the most serious of these is the Monterey pine cone beetle *(Conophthorus radiatae)* that attacks maturing cones in central California but does not damage the more southerly population.

Animal damage to ornamental plantings can be a problem but generally is not serious. On Guadalupe Island, however, chronic overgrazing by goats has virtually eliminated Monterey pine regeneration.

Special Uses

The wood of Monterey pine is light, soft, brittle, and coarse-grained. The trunk is characterized by a large amount of crook and other irregularities, a small percentage of clear bole, and frequent presence of disease. These characteristics cause the species to be of little commercial value for lumber and wood products in the United States. Past commodity use has been for coarse lumber in a localized market and for fuelwood. In marked contrast, the species is valued for wood products in many other countries.

A major use of this pine is as an ornamental in parks and urban areas. The species often is planted in areas devoid of trees where its rapid growth and attractive foliage quickly provide variety and contrast to the landscape. The pine also is planted extensively to help establish vegetative control of eroding and blowing soils. Prized as a living screen against wind, noise, and traffic, Monterey pine graces many a boulevard and backyard in urban areas. It also has been asexually propagated for Christmas trees (33).

In its native habitat and particularly near the ocean, the rugged, picturesque, wind-battered trees deserve special mention for their esthetic appeal. Stands near Carmel, CA, are among the most photographed in the world.

Genetics

Population Differences

The three mainland populations of Monterey pine, although disjunct, grow where climate and soil are similar. A large proportion of the total phenotypic variation in several branch, needle, and cone characteristics, however, is observed between individual trees at each location. The Cambria population, although less variable than the other two, differs from them in several cone, branch, and needle characteristics. In Australia these differences, plus a slower growth rate and a different pattern of seasonal growth, suggest that the Cambria population differs genetically from the northern populations *(11)*. A recent study, however, indicates little genetic differentiation among the native populations. Most of the genetic variation is located within each stand *(26)*.

Hybrids

No evidence of widespread introgression from knobcone or bishop pine has been found, although hybridization is occurring locally between Monterey and knobcone pines at Año Nuevo *(11)*. The hybrid is designated *Pinus attenuata x radiata* Stockwell & Righter. The two-needled pine found on Guadalupe and Cedros Islands is currently named *P. radiata* var. *binata*.

The unique characteristics of rapid growth, large genetic variability, and ease of vegetative propagation have made Monterey pine the subject of intensive genetic improvement programs in several countries, notably Australia and New Zealand.

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