Quercus kelloggii Newb. California Black Oak

Fagaceae Beech family

Philip M. McDonald

California black oak *(Quercus kelloggii)* exceeds all other California oaks in volume, distribution, and altitudinal range. Yet this deciduous hardwood has had little sustained commercial use and almost no management, even though its wood closely resembles that of its valuable, managed, and heavily used counterpart-northern red oak (Quercus *rubra)*—in the Eastern United States.

First collected in 1846 near Sonoma, CA, the species was not named until 1857 when John Newberry called it *kelloggii* in honor of Albert Kellogg, a pioneer California botanist and physician (17). In later botanical works, the species was called Q. *californica* and black oak or Kellogg's oak.

Acorns of California black oak were carried from San Francisco to England in 1878. Thirty-two years later, trees from these acorns were described as being 30 feet tall and making good growth *(10)*.

Habitat

Native Range

The north-south range of California black oak (fig. 1) is about 1255 km (780 mi). In Oregon, its natural range extends from just north of Eugene, southward through the valleys west of the Cascade Range. The species is especially frequent along lower slopes in fairly dry sections of the Klamath and Cascade Mountains but never grows near the Pacific Ocean. In California, black oak is found in the northern Coast Range from the Oregon State line to Marin County and then intermittently in the Santa Cruz and Santa Lucia Mountains. This oak becomes more common on the San Bernardino, San Jacinto, and Agua Tibia Mountains, extending to just south of Mt. Laguna, and is now recognized as being in Baja California (5). In California's Sierra Nevada, the species grows abundantly along the west side, from near Lassen Peak to near Kings Canyon. California black oak becomes intermittent southward to the Tehachapi Mountains, where it again increases in abundance. California black oak is generally confined to the westside, but a few stands have been found along the eastside of the Sierra Nevada. The species approaches the Nevada State line northeast of Beckwourth Pass but is not reported in Nevada.

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Climate

Hot dry summers and cool moist winters characterize the climate where California black oak grows. Within the species' natural range, average annual precipitation varies widely. In the valleys of southwestern Oregon, it exceeds 760 mm (30 in); in northwestern California, it ranges from 760 to 2540 mm (30 to 100 in); and in northeastern California, only 300 to 380 mm (12 to 15 in) of rainfall annually. Throughout the range of black oak in north-central and central California, annual precipitation averages 1010 to 1780 mm (40 to 70 in) but may exceed 2920 mm (115 in) locally. In these areas less than 4 percent of the yearly precipitation falls from June through September. In the mountains of southern California, precipitation averages 910 mm (36 in). Black oak achieves its best size and abundance in areas where snowfall accounts for 10 to 50 percent of the year's precipitation.

Average mean daily temperatures range from -1" to 8" C (31" to 46" F) during January, and from 19" to 28" C (66" to 82" F) in July. The last killing spring frost is expected between March 15 and June 9, and the first killing frost in the fall between August 30 and November 30. Periods free of killing frosts range from 82 to 270 days. Throughout an 18-year period, the highest temperature recorded at 1125 m (3,700 ft) elevation in the center of black oak's zone of greatest size and abundance was 39" C (103" F); the minimum temperature was -15" C (5" F). The maximum number of frost-free days was 215 and the minimum was 116 (35).

Soils and Topography

Probably the most important single soil variable that limits the presence of California black oak is internal drainage. Black oak is not found growing "with its feet wet." The species is adapted to soils derived from diverse parent materials-andesite, basalt, granite, pumice, quartz diorite, sandstone, schist, shale, and volcanic tuffs and breccias. California black oak only rarely is found on soils originating from serpentine. Occasionally it grows on soils derived from ultrabasic parent material, but mostly where above-average amounts of calcium seem to offset the deleterious effects of magnesium.

Soil textures favoring this oak range from medium-textured loams and clay-loams to the more coarse-textured gravelly-clay-loams and sandy-loams. In-

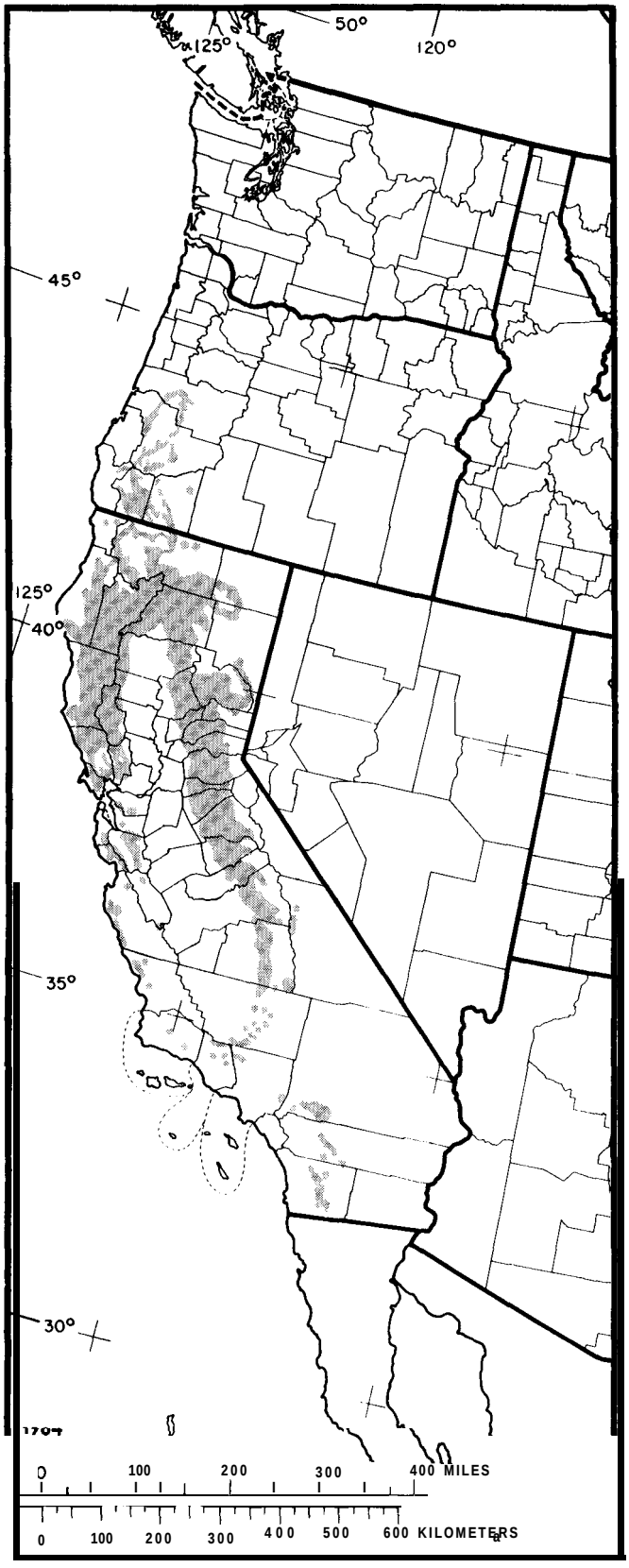

Figure 1—*Native range of California black oak.*

creasing clay content in the surface soil usually means a decreasing incidence of black oak. In fact, this species rarely is found on soils with clay topsoils, particularly if the clay is heavy and sticky. Black oak usually grows on thin soils and rocky slopes, but always at the cost of abundance or form, or both. In general, black oak grows best on medium- to coarse-textured, deep, and well-drained soils.

About 75 soil series in California have been identified by the California Cooperative Soil-Vegetation Survey and the National Cooperative Soil Survey as supporting California black oak. Important soil series in the California Coast Range include Boomer, Cohasset, Josephine, Sites, and Sheridan. In the Sierra Nevada, Aiken, Chawanakee, Holland, Stump Springs, Corbett, and Tish Tang support abundant black oak. Soils in the southern Cascade and Klamath Mountains that often are clothed with black oak include Aiken, Cohasset, McCarthy, Sites, Tournquist, Behemotosh, Horseshoe, and Neuns. Fourteen soil series have been identified in Oregon, mostly on series similar to those in California. Most of the soils in both States are found at higher elevations and support forest vegetation rather than oak woodland or chaparral. Soil orders are mostly Alfisols and Inceptisols, occasionally Mollisols.

The best black oak stands in the Coast Range and Klamath Mountains are found on deep, slightly acid loams and gravelly-clay-loams derived from sandstone and shale. In the southern Cascade Range and northern Sierra Nevada, black oak grows best on deep loams and clay-loams originating from metavolcanic rocks. In the central and southern Sierra Nevada and in the Transverse and Peninsular Ranges, this oak grows well on deep, acid to moderately acid sandy-loam soils derived from granitic rock.

California black oak grows within a wide elevational range-from the level gravelly floors of low valleys to alluvial slopes, rocky ridges, and high plateaus. Most of the terrain is rugged, steep, and dissected by major streams and ephemeral drainages.

In Oregon, the elevational range of black oak varies from 137 m (450 ft) near Eugene, to more than 305 m (1,000 ft) on the low rounded hills in the Umpqua River drainage ***(13).*** The oak also is found within this elevational range on the eastern slopes of the Coast Range and the western slopes of the Cascades. In south central Oregon and the Klamath Mountains, black oak grows at higher elevations of 610 to 915 m (2,000 to 3,000 ft).

In California's Coast Range, black oak is found from about 152 m (500 ft) along the Mattole River in Humboldt County to 1830 m (6,000 ft) in the Yolla Bolly Mountains. Black oak reaches its lowest eleva-

tion (60 m or 200 ft) in the Napa and Santa Rosa Valleys. Most black oak in the central portion of the Coast Range grows between 305 to 1525 m (1,000 to 5,000 ft), gradually increasing in elevation but narrowing in range to 1220 to 1982 m (4,000 to 6,500 ft) in Santa Barbara and eastern Ventura Counties. Farther south in the Transverse Range the species is found at elevations of 1403 to 2135 m (4,600 to 7,000 ft) (39). In the San Jacinto Mountains, black oak reaches 2440 m (8,000 ft) and, at its southernmost extension in the Peninsular Range of San Diego County, it grows within the 1525- to 1830-m (5,000- to 6,000-ft) elevation.

The elevational range of black oak in California's Cascade Range is from about 183 m (600 ft) in western Shasta County to 1906 m (6,250 ft) in south-central Shasta County. In the Sierra Nevada, lower elevational limits for black oak range from 458 m (1,500 ft) in the north to 1220 m (4,000 ft) in the south. Upper limits increase north to south from about 1982 to 2380 m (6,500 to 7,800 ft).

California black oak is most abundant and attains its largest size in the Sierra Nevada. Extensive stands of excellent development also are found in eastern Mendocino and Humboldt Counties of the north Coast Range. Elevation and aspect often interact to govern abundance and development. At elevations below 305 m (1,000 ft) in north-central California, black oak is found primarily in sheltered draws or on north slopes. With increasing elevation, favorable aspects increase until at 762 to 915 m (2,500 to 3,000 ft) all aspects support California black oak, providing soil is deep enough. Above 1067 m (3,500 ft), north- and east-facing slopes often are devoid of black oak, although other vegetation grows well. In the southernmost mountains, black oak is found on west-facing slopes, but only where soils are deep, temperatures are cool, and soil moisture is adequate.

Associated Forest Cover

California black oak is a component of six forest cover types *(11)*. It is the prime constituent of California Black Oak (Society of American Foresters Type 246) and a major component in two others: Douglas-Fir-Tanoak-Pacific Madrone (Type 234) and Pacific Ponderosa Pine-Douglas-Fir (Type 244). Black oak becomes important in Sierra Nevada Mixed Conifer (Type 243) and Pacific Ponderosa Pine (Type 245) after severe disturbance or fire. The oak is a minor component in Canyon Live Oak (Type 249).

The successional status of California black oak is not clear. It has been implied that the species was climax because the type in which it was a part represented a degree of mesophytism between that of the chaparral and the conifer forest (7). The species was also thought to be more a persistent subclimax than climax.

California black oak, or its fossilized equivalent *(Quercus pseudolyrata),* was much more widespread in past ages than now. Fossil remains indicate that the species was abundant in sedimentary deposits near Spokane and Ellensburg, WA, in the John Day Valley and Blue Mountains of Oregon, and in northwestern Nevada (6). These deposits date back to the Miocene epoch of 12 to 26 million years ago. Increasing aridity is the probable cause for the smaller natural range of black oak today.

The most common botanical associate of black oak is ponderosa pine *(Pinus ponderosa* var. *ponderosa).* The two species intermingle over vast acreages, except that black oak is found at lower elevations, on sites too poor to support pine, and in certain areas within the redwood region of California where pine does not grow. Another exception is that this oak is rarely found in Interior Ponderosa Pine (Type 237) *(11)*. In California and Oregon, therefore, where the natural ranges of the two species coincide, ponderosa pine sites generally are fertile ground for black oak. And black oak sites are almost always fertile ground for ponderosa pine.

At lower elevations, black oak often serves as a nurse tree to conifers. Ponderosa pine, Douglas-fir *(Pseudotsuga menziesii),* and incense-cedar *(Libocedrus decurrens)* seedlings often become established beneath the sheltering crowns of large black oaks while adjacent ground remains bare (2).

A rule-of-thumb is that black oak never grows through a stand of ponderosa pine but can grow through brush (9). Without disturbance, black oak is eventually crowded out of the best sites and remains only as scattered remnants in mixed-conifer forests. Here it often exists on "islands" of soil or terrain not favorable for natural regeneration of conifers.

Black oak grows individually or in groves, some of which are quite extensive. Usually each grove is of one age-class, the result of sprouting after fire (34). Rarely does it exist as an understory, especially beneath a closed canopy. The species is usually a component of hardwood stands or of mixed hardwood and conifer forests. Tanoak *(Lithocarpus densiflorus)* and Pacific madrone *(Arbutus menziesii)* are the most common hardwood associates of black oak. Other hardwood associates at lower elevations are Oregon white oak *(Quercus garryana),* interior live oak *(Q. wislizenii),* coast live oak *(Q. agrifolia),* Engelmann oak *(Q. engelmannii),* and blue oak (Q. *douglasii).* At higher elevations Pacific dogwood *(Cornus nuttallii),* bigleaf maple *(Acer macrophyllum),*

California-laurel *(Umbellularia californica),* and canyon live oak *(Quercus chrysolepis)* intermix with California black oak.

Besides ponderosa pine, conifer associates at low elevations are knobcone pine *(Pinus attenuata),* Monterey pine *(P. radiata),* Digger pine *(P. sabiniana),* and redwood *(Sequoia sempervirens).* At intermediate elevations within the natural range of California black oak are California white fir *(Abies concolor* var. *lowiana),* grand fir *(A. grandis),* incense-cedar, Coulter pine *(Pinus coulteri),* sugar pine *(P. lambertiana),* giant sequoia *(Sequoiadendron giganteum),* Douglas-fir, California torreya *(Torreya californica),* and bigcone Douglas-fir *(Pseudotsuga macrocarpa).* At higher elevations black oak intermingles with western juniper *(Juniperus occidentalis)* and Jeffrey pine *(Pinus jeffreyi).*

Shrub associates include at least 30 species, some of the most important of which are greenleaf manzanita *(Arctostaphylos patula),* whiteleaf manzanita *(A. viscida),* deerbrush *(Ceanothus integerrimus),* bear-clover *(Chamaebatia foliolosa),* oceanspray *(Holodiscus discolor),* Brewer oak *(Quercus garryana* var. *breweri),* Sierra coffeeberry *(Rhamnus rubra),* Sierra gooseberry *(Ribes roezlii),* and poison-oak *(Toxicodendron diversilobum).* In parts of Shasta and Trinity Counties, and perhaps elsewhere, black oak itself takes a shrub form. The stands so formed usually are dense and tangled-ideal habitat for deer and upland game.

Except on the fringe of black oak's natural range, especially at the lowermost elevations, most shrubs generally are not competitive, nor particularly abundant over most of the forest land where black oak grows. After heavy cutting or fire, however, some of the more aggressive shrubs often compete strongly with black oak sprouts.

When compared with 15 of its most common shrub associates in the Klamath Mountains of northern California, black oak ranked ninth in need of soil moisture, third in demand on soil nutrients, eighth in terms of tolerance, and first in rapidity of sprouting (32). The species is able to withstand high moisture stress (37) and to become established and grow well on harsh sites where few other species are capable.

Life History

Reproduction and Early Growth

Flowering and Fruiting-California black oak flowers from mid-March to mid-May depending on elevation, physiography, and local climatic conditions. In general, trees near the coast and at lower elevations bloom earliest.

Flowers on black oak are unisexual. The plant is monoecious. Staminate flowers are long (3.5 to 7.5 cm or 1.4 to 3.0 in) hairy aments that emerge from buds in the leaf axils of the previous year's growth. The five to nine stamens in each ament have bright red anthers and pale green filaments. The calyx is light green. Pistillate flowers are borne singly or two to seven on a short stalk that originates from leaf axils of the current year's growth. The stigmas are dark red.

Acorns mature in the second year. Early in the second summer the immature acorn resembles a small globe about 6 mm (0.2 in) in diameter. At this stage, the acorn is completely encapsulated in the cup. At maturity the light brown, thin-scaled cup encloses from 0.5 to 0.75 of the acorn. Acorns form singly, or in clusters of two to six, and vary widely in dimension. Sizes range from 1.9 to 4.4 cm (0.7 to 1.7 in) long and from 0.9 to 3.8 cm (0.4 to 1.5 in) in diameter.

Seed Production and Dissemination-In natural stands, black oak must be 30 years or older before it produces viable seed. The oak produces some acorns sporadically between ages 30 and 75, but seldom large quantities before 80 to 100 years. A few trees bear at least some acorns every year. Others of similar diameter and crown characteristics rarely produce acorns. Trees that are good seed producers continue abundant acorn production at least to 200 years.

Age, diameter of bole, and crown width influence acorn yield *(22).* A general relationship for a medium seed crop on a good forest site is that acorn yield increases as bole and crown diameter increase, at least through age 200:

Ase	Bole diameter		Crown diameter		Acorn vield	
yr	*cm*	*in*	*m*	*ft*	*kg*	*lb*
30	13	5	5	15	0	0
50	23	9	6	20	2	5
80	33	13	8	26	9	20
100	43	17	10	32	27	60
150	61	24	12	41	45	100
200	81	32	16	52	64	140

Estimates of acorn production by tree or size of seed crop are scarce. One large, 150- to 200-year-old black oak in Butte County, CA, produced about 6,500 acorns for a crop year rated as fair. Acorns were large and heavy, numbering 115/kg (52/lb). Black oak acorns usually are smaller, numbering between 115 and 324/kg (52 and 147/lb). Large acorns have been

observed at both low and high elevations and small acorns at medium elevations. The factors influencing acorn size probably are many, but little is known about their interaction. A single, large, well-developed tree at a low elevation in Shasta County, CA, produced sound acorns each year as follows:

1974	700
1975	1,000
1976	65
1977	0
1978	320
1979	231
1980	125

The magnitude and periodicity of seed crops appear to be quite variable. One study reported that abundant seed crops for entire stands were produced at 2- to 3-year intervals *(31)*. At 760 m (2,500 ft) elevation in Yuba County, CA, medium to bumper seed crops were produced in 4 of 20 years. At 850 m (2,800 ft) elevation in south-central Shasta County, medium to bumper crops were borne on large black oaks in 4 of 8 years. At a lower elevation in Shasta County (170 m or 560 ft), black oaks yielded sound acorns in 6 of 7 years. Of these, two each rated as bumper, medium, and light.

Insects destroy many acorns, primarily in the developmental stage. Immature acorns are attacked by both lepidopterous and coleopterous pests. The filbertworm (*Melissopus latiferreanus)* and the filbert weevil ***(Curculio uniformis)*** are particularly destructive, in some places infesting up to 95 percent of the acorns and destroying most of a crop *(16)*. Fire may lessen these losses. On the Shasta-Trinity National Forests in California, a prescribed burn in March 1978 resulted in a bumper crop of sound black oak acorns, while trees on unburned ground nearby bore only unsound acorns. Apparently, destructive insects in the duff and soil were reduced greatly by the fire *(33)*.

Fully developed acorns begin falling in mid-August at lower elevations, and in mid-September at higher elevations. Almost all acorns that fall first are hollow or infested with insects. Some are still green or greenish yellow. Sound acorns begin dropping from late September to early November and cease by November 15 at lower elevations. At higher elevations almost all acorns have fallen by early December.

Acorns generally drop just before or during leaf fall. Once on the ground, temperature can be critical to continued viability, and fallen leaves help keep acorn temperatures below lethal thresholds. In one instance, fully mature acorns exposed to the hot fall sun had withered cotyledons after 9 days. Acorns from the same trees showed full-sized cotyledons after 21 days, if protected by leaves and branches *(21)*. Likewise, cotyledons of acorns exposed to freezing temperatures turned gray and flaccid, although cotyledons of acorns beneath tree crowns and covered with leaves remained white, crisp, and firm.

A blue-gray mold also damages fallen seed. At one location, acorns covered for about 2 months by wet leaves showed mold at the blunt ends that had progressed well within the seeds. For other acorns in this same environment, cutting tests showed that cotyledons were unaffected. American Indians, however, gathered only freshly fallen acorns to avoid the mold *(15)*.

Because the acorns are large and heavy, most fall directly beneath tree crowns. Few bounce or roll far on steep slopes covered by duff, leaves, and litter. Animals play a vital role in dissemination of acorns because they transport some of them away from the parent tree. The western gray squirrel and the scrub jay are the most important disseminators, for they bury the acorns, sometimes spreading the species to areas nearby.

Black oak acorns are eaten by at least 14 species of song and game birds, many species and subspecies of small mammals (mostly rodents), and mule deer *(20)*. Black bears in the San Bernardino Mountains of southern California utilize the California black oak type in spring, summer, and fall (28). For many of these creatures, acorns are the primary foodstuff in the fall. Without acorns, populations are affected. Fawn survival rates, for example, increase and decrease with the size of the acorn crop.

Cattle, and, to a lesser extent, sheep, also consume many black oak acorns each year.

Seedling Development-California black oak reproduces from seed, but natural regeneration tends to be scanty, poorly distributed, and uncertain. The most likely place to find black oak seedlings is beneath large parent trees, where they number up to 45/m^2 (4/ft^2).

Before the seeds begin to germinate, a period of after-ripening to overcome dormancy is required. Over-wintering beneath the litter on the forest floor normally breaks dormancy under natural conditions. For artificial regeneration, acorns can be stratified by cold storage in sealed polyethylene bags thick enough to inhibit moisture loss, but porous enough to freely emit respiration byproducts. Storage temper-ature should be just above freezing and moisture content of acorns maintained at a level where cotyledons are turgid or slightly flaccid, but not dried out.

Natural seedbed requirements for germination are not exacting. Either undisturbed leaflitter or, to a lesser extent, moist, well-aerated mineral soil are

good seedbeds. Establishment of black oak is almost nonexistent on heavy clay soils or soils compacted by logging machinery. These conditions reduce the ability of the radicle to penetrate the soil far enough and fast enough to avoid searing soil surface temperatures or the seasonal drying of upper soil layers.

Acorns germinate in the spring when the weather warms. Germination is hypogeal and highly variable, both in magnitude and timing. The radicle is first to emerge and grows downward for some time, often 10 to 20 days, before the epicotyl appears above ground. This process benefits the seedling in getting to and staying in available soil moisture, and in minimizing transpirational losses. Sometimes a single acorn may put forth several epicotyls, particularly if upward progress is hampered by a stony or crusty soil.

Under optimum conditions, 15 to 25 days elapse between sowing of stratified acorns and the beginning of germination. In nature, the germination period may be several weeks or even months. Germinative capacity varies considerably and changes with degree of insect infestation, amount of mold, and depth of acorn in soil, among other variables. Germination has been reported as high as 95 percent and also as scanty (21 percent). Germinative capacities in large-scale field tests in the northern Sierra Nevada were 31 and 38 percent (22).

Black oak seedlings often reach heights of 10 to 15 cm (4 to 6 in) and extend their taproots downward as deep as 76 cm (30 in) in the first growing season. Development of a deep-thrusting vertical root is necessary for seedlings to cope with the hot dry summers characteristic of California black oak's range. For the first few years, therefore, both lateral root development and shoot growth are slow. Shoot growth probably does not begin to accelerate until root capacity is extensive enough to obtain adequate moisture. This may take 6 or 7 years or longer. Shoot growth of some seedlings, particularly those stressed by competing vegetation, never accelerates and these seedlings eventually die.

Studies evaluating artificially regenerated California black oak on the Plumas and Angeles National Forests in California indicate that artificial regeneration of black oak is possible, providing that competing vegetation and pocket gophers are controlled. Fall planting of l-year-old seedlings, without artificial watering, resulted in good survival and growth on the San Bernardino National Forest, California *(30)*.

Fertilization appears to be one technique for enlarging root capacity and stimulating height development of seedlings. In a test in the northern Sierra Nevada, fertilized seedlings were more than three times taller than unfertilized seedlings (0.2 as against 0.8 m or 0.7 as against 2.5 ft) after five growing seasons. Fertilizer in the proportion of 16-20-0 for nitrogen, phosphorus, and potassium was applied at about 0.1 kg (0.25 lb) per seedling early in the spring of each year (22).

Young black oak seedlings are killed mostly by drought and pocket gophers. Grasshoppers and other insects damage young seedlings, and freezing by late spring frosts injures them. These injuries usually are mitigated by sprouting from the root crown.

Vegetative Reproduction-California black oak sprouts profusely after trees are cut or burned. Most sprouts develop from latent buds, which lie under the bark at, or slightly above, the root collar. Other sprouts originate from the top of the stump or between the top and the ground. These are called stool sprouts and are undesirable for two reasons. They are weakly attached to the parent stump and frequently broken off by wind and snow, and are prone to heart rot at an early age.

The size and vigor of the parent tree determine the number of sprouts and their height and crown spread. In general, stumps from larger trees produce a larger number of sprouts and more vigorous ones. Only old, moribund trees fail to produce sprouts after cutting.

Low stumps of nearly all diameters produce many more sprouts than high stumps. High-stumping an older, larger tree yields undesirable stool sprouts, and often no sprouts from below ground.

Root crown sprouts grow vigorously, especially in full sunlight. Forty-nine stumps were studied in stands on a good site in the northern Sierra Nevada. Sprout density, height, and crown width were evaluated in clearcuttings and in shelterwood stands where 50 percent of the basal area had been removed (22). Number of sprouts, crown width, and especially height growth were consistently greater in the clearcuttings (table 1).

The environment typical of shelterwood cuttings apparently is more favorable to a cynipid gall wasp *(Callirhytis perdens)* than that in clearcuttings. Damage to terminal shoots by this pest is greater under shelterwood stands, accounting in part for the poorer height growth of sprouts. Thinning sprouts to three or four per stump at age 4 showed no gain in height but resulted in undesirable damage to the bole from sunscald and increased forking of stems *(22)*.

Young black oak sprouts grow faster in height than other vegetation, including coniferous associates. Consequently, they remain dominant for many years. Although black oak seedlings extend the species into new areas, sprouts keep the oak in the same area

and are responsible for regenerating many more stands than seedlings. Only after the living crown has moved considerably up the bole does black oak begin its role as a nurse tree, aiding conifers to become established and grow to equal or dominant positions in the stand.

Propagation by layering, rooting of cuttings, or grafting has not been reported. But the wartime shortage of cork in the 1940's stimulated grafting of cork oak ***(Quercus suber)*** to black oak stocks. In a greenhouse trial, 70 percent of the grafts were successful (27).

Sapling and Pole Stages to Maturity

Growth and Yield-Because fire incidence throughout its natural range is high, nearly all black oak trees originated from sprouts. Consequently most California black oak stands are even-aged.

Number of sprouts per stump influences growth, form and, eventually, yield. The number per clump decreases rapidly with age. By the time the sprouts are pole-size, competition within individual clumps has reduced them to two or three, or occasionally, four stems. By age 100, only one or two stems remain. These data are based on 180 clumps at many California sites ***(21).***

The form of California black oak varies greatly. On the fringe of its range and on marginal sites, black oak trees assume a scrubby form. In closed stands on good sites, the oaks tend to be tall and straight with clear boles and thin crowns. When open-grown, black oaks generally fork repeatedly, becoming multi-stemmed and broad-crowned.

The general age-height relationship of California black oak, based on 393 dominant trees in northern and central California, is curvilinear until age 140. Thereafter, tree height remains constant regardless of age. Selected age-heights are 20 years, 8 m (26 ft); 40 years, 13 m (43 ft); 60 years, 17 m (56 ft); 100 years, 22 m (72 ft); and 140 years, 25 m (82 ft) ***(21).***

Position on long continuous slopes also influences growth and form. Trees at the toe of slopes or on gently sloping benches, where deeper soils are likely, generally grow best and have good form. Those at midslope are shorter and more scrubby. On upper slopes, trees grow slowly and are even shorter. Aspect also influences growth. Of the 393 trees noted earlier, loo-year-old trees averaged about 26 m (85 ft) in height on east aspects; 22 m (72 ft) on north aspects; 21 m (68 ft) on west; and 17 m (56 ft) in height on south aspects.

Average site index at base age 50 years is about 15 m (50 ft); better than average, about 18 m (60 ft); and poor, only 11 to 12 m (35 to 40 ft) (29).

Diameter growth is often slow during the first 25 years of a black oak's life. Competition for position in the canopy tends to favor height growth over diameter growth. At 25 years, the average tree is nearly 11 m (35 ft) tall and about 10 cm (4 in) in d.b.h. and is one of three sprouts in the clump. Black oak grows fastest in diameter from age 25 to 65 (table 2). Its growth can reach one ring per centimeter or three rings per inch. At age 65 the tree is about 29 cm (11.5 in) in d.b.h. and has grown almost 0.5 cm/yr (0.2 in/yr).

Table l-Development of California black oak stump sprouts in a northern Sierra Nevada forest 10 years after cutting

Year after cutting	Sprouts per stump		Height		Crown width	
	Clear-cut	Shelter-wood	Clear-cut	Shelter-wood	Clear-cut	Shelter-wood
	no.		*m*			
0	55+	28	—		—	—
2	55+	23	1.2	0.9	1.2	0.7
4	35	17	2.4	1.2	1.8	1.0
6	23	15	3.7	1.5	2.3	1.2
6	18	13	4.9	1.8	2.6	1.6
10	15	12	6.0	2.1	2.9	2.2
	no.		*ft*			
0	55+	28	—	—	—	—
2	55+	23	4	3	4	2
4	35	17	8	4	6	3
6	23	15	12	5	8	4
8	18	13	16	6	9	5
10	15	12	20	7	10	7

Black oak in an understocked stand averages 33 to 35 cm (13 to 14 in) in d.b.h. at 65 years; in an overstocked stand, it averages between 18 and 23 cm (7 to 9 in). After age 65, diameter growth slowly declines. By age 90 most trees are mature.

Diameter growth of California black oak can be increased greatly by thinning. On a good site in the northern Sierra Nevada, diameter growth rates of trees thinned when 60 years old were twice that of unthinned trees of similar age 8 years after thinning *(23)*.

Black oak may live to be almost 500 years old, but age-diameter relationships beyond 120 years are uncertain. Trees 51 cm (20 in) in d.b.h. can range between 70 and 175 years. Trees 41 to 63 cm (16 to 25 in) in d.b.h. were 175 to 275 years old, and those more than 102 cm (40 in) were 175 to 325 years old (fig. 2).

Black oak seldom exceeds 1.5 m (5 ft) in d.b.h. or 40 m (130 ft) in height. The largest living black oak

Figure 2—*California black oak near Shingletown, Shasta County, CA; it is nearly 37 m (121 ft) tall, 159 cm (63 in) in d.b.h., and 180 years old.*

Figure 3—*Interior view of a natural 70-year-old California black oak stand of average stocking, density, and growth rate. Trees average 30 cm (12 in) in d.b.h. and more than 18 m (60 ft) in height.*

Table 2-Diameter growth in natural stands, California black oak, 1968[1]

Age	D.b.h.		Average cumulative increment per decade	
yr	*cm*	*in*	*cm*	*in*
20	9	3.4	4.32	1.70
30	14	5.4	4.57	1.80
40	18	7.2	4.57	1.80
50	23	9.0	4.57	1.80
60	27	10.8	4.57	1.80
70	31	12.2	4.42	1.74
80	34	13.4	4.27	1.68
90	37	14.6	4.11	1.62
100	40	15.6	3.96	1.56
110	42	16.6	3.84	1.51
120	44	17.5	3.71	1.46

[1]Basis: 405 dominant trees in 45 even-aged stands, many California sites

known measures 274 cm (108 in) in d.b.h. and 37.8 m (124 ft) in height. This tree grows in the Siskiyou National Forest, OR *(1).*

Yield data are difficult to find. The "average" stand (fig. 3) contains 1,086 trees per hectare (440/acre), 8.9 cm (3.5 in) and larger in d.b.h., and would yield slightly more than 409 m^3/ha (5,845 ft^3 or 65 cords/acre). In 60-year-old mixed-hardwood stands on good sites in the northern Sierra Nevada, black oak produces 76 m^3/ha (1,085 ft^3 or 12.1 cords/acre).

Rooting Habit-Various investigators have described the rooting system of black oak as having no taproot but large spreading roots *(18);* as deep and long lived; with a strong taproot; and possessing strong laterals, more or less deep, depending on depth to ground water (3).

Observations at road cuts indicate the general rooting pattern of this oak. Usually, from one to several vertical roots extend through the soil and penetrate to rock. Then they become lateral and spread out directly above the rock. At fissures, "sinker" roots penetrate the rock itself. A number of roots are found near the surface, probably to exploit the nutrients there.

Reaction to Competition-The tolerance of black oak to shade varies with age. It most accurately can be classed as intolerant because this condition exists throughout most of its life (9). The oak is moderately tolerant in early life, growing well in full sunlight but persisting in dense shade *(31).* As a sapling and small pole, black oak is less tolerant and often grows tall and thin until it reaches a position in the canopy where it can receive light. The need

for top light increases as the tree ages. In dense stands, black oak often fills a "hole" in the canopy, sometimes leaning 15 to 20 degrees to do so. If overtopped, the oak either dies outright or dies back successively each year. Short epicormic branches keep the tree alive for a time, but with continued overtopping, death is inevitable.

Damaging Agents-Fire is black oak's worst enemy. Crown fires kill trees of all ages and ground fires are often fatal, Only a little radiative heat kills the cambium and only a small amount of flame along the trunk leaves long vertical wounds. Bark thickness on mature trees varies from 2 to 5 cm (1 to 2 in), but even the thickest bark provides little insulation to fire. Scars from burning can become a point of entry for fungi. On larger trees, repeated fires often enlarge old scars, sometimes toppling the tree. Fluctuations in weather also cause injury Heavy, wet snow breaks branches and stems, particularly at forks, and sudden high temperatures following cool wet weather severely injure leaves (25).

California black oak is especially susceptible to fungi. Heart rot of the bole and large limbs of living trees, caused mainly by two pathogens, ***Inonotus dryophilus*** and ***Laetiporus sulphureus,*** is the principal damage (24). These rots enter the tree through broken branches or open wounds resulting from fire or logging. Both fungi often reduce the bole and large limbs of older, decadent trees to mere shells. The hedgehog fungus ***(Hydnum erinaceus)*** also is found in the heartwood of living trees and ***Polyporus adustus*** in the sapwood, though neither is prevalent.

By the time a natural black oak stand is 85 years old, the proportion of infected trees begins to increase rapidly. Almost 40 percent of trees 110 to 120 years old show incipient heart rot (21). Rotation age of stands grown for wood products could be influenced by this incidence-age relationship.

Another serious pathogen, ***Armillaria mellea***, causes decay of the roots and butt of older decadent black oak. Sometimes it weakens the root system so much that the tree topples over on a perfectly calm, still day (36). This pathogen is indigenous in black oak, but younger vigorous trees do not seem to be affected by it.

A comparatively recent damaging agent to black oak in the San Bernardino Mountains of southern California is air pollution. Although the oak appears less susceptible to air pollution damage than associated conifers, radial growth has decreased in some trees (12). Where high ambient oxidant air pollution levels are chronic, damage to California black oak is expected to be significant (26).

One virulent pathogen that black oak escapes, and indeed is resistant to, is ***Heterobasidion annosum*** (14). For this reason, California black oak is being planted in numerous infection centers in southern California forests where conifers are dead or dying.

California black oak is prone to several leaf diseases including the oak leaf fungus ***(Septoria quercicola)***, oak anthracnose ***(Gnomonia veneta),*** powdery mildews ***(Microsphaera*** and ***Sphaerotheca*** spp.), a leaf blister fungus *(Taphrina caerulescens),* a leaf rust ***(Cronartium*** spp.), and true mistletoe ***(Phoradendron villosum*** subsp. ***villosum).*** Damage from each of these pests has not been determined but loss of growth increment probably is minor.

Animal damage to black oak is mostly from browsing. Foliage is eaten during all seasons, but especially in spring when new growth is tender and in winter when twigs are eaten. Deer eat acorns, seedlings, sprouts, and foliage. Even in midsummer, newly germinated seedlings with acorns attached often are consumed (8). Occasionally, browsing is fatal. In Mendocino County, CA, for example, a deer population of 1/2.4 ha (1/6 acres) almost eliminated oak over large areas of the Coast Range. Cattle also browse black oak, but in national forests, at least, their numbers are declining.

Many insects derive sustenance from black oak. The damage is usually secondary, reducing growth but seldom killing trees. Among sucking insects, the pit scales ***(Asterolecanium minus*** and ***A. quercicola)*** have the greatest potential for damage (4). The most destructive insect, however, is probably the carpenterworm ***(Prionoxystus robiniae),*** whose larvae mine the wood of trunk and limbs and cause injuries that appear later as defects in lumber *(16).*

Other insects are capable of heavy damage, especially when infestations become epidemic. The Pacific oak twig girdler *(Agrilus **angelicus)*** is the most damaging insect to oak in southern California during drought years (4). In northern California, the California oakworm ***(Phryganidia*** *californica)* is noted for defoliating trees. So is the fruit-tree leafroller *(**Archips argyrospila)*** which, in 1968, caused heavy damage throughout a wide area in the Sacramento River drainage.

Special Uses

Several attributes qualify the wood of California black oak for commercial use: attractive grain and figure for paneling and furniture, hardness and finishing qualities for flooring, and strength properties for pallets, industrial flooring, and other uses (19). The forks of open-grown black oaks were put to good use in the 1870-80's in Mendocino County.

Those of specific dimensions were used as "naturally assembled" ship keels and ribs. Wood products currently produced are high grade lumber and pallets, industrial timbers, sawdust for mulching, and bulk and prepackaged firewood. The wood is prized for fuelwood and in some areas unrestricted cutting is eliminating oak stands.

Although not presently utilized, black oak acorns, high in edible oils, are a potential source for thousands of tons of human food (38).

Genetics

Two natural hybrids are recognized: Quercus x *ganderi* C. B. Wolf *(Q. agrifolia x Q. kelloggii)* and *Quercus x moreha* Kellogg *(Q. kelloggii x wislizenii)*. Another hybrid, *Quercus x chasei (Q. agrifolia x kelloggii)* has been described in Monterey and Santa Clara Counties, CA.

Of the hybrids, *Q. moreha* is by far the most widespread, ranging throughout California and even found, though rarely, in south-central Oregon. The tree is distinguished readily in the winter by its sparse evergreen foliage in contrast to the completely deciduous black oak. New leaves in spring form a dense mass of shiny green foliage on the hybrid.

Forma cibata, a form by which black oak has been described, is a low shrub common to steep, rocky, talus slopes at higher elevations. Although described as a true shrub form, this status is questionable. No criteria are known for distinguishing between it and scrubby black oak trees.

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