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Oak Management in California

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Cover: A stand of old-growth valley oak (*Quercus lobata* Née) in Tehama County, California.

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IN BRIEF

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Interest in native California oaks is increasing. Species like California black oak (*Quercus kelloggii* Newb.), blue oak (*Q. douglasii* Hook. & Arn.), coast live oak (*Q. agrifolia* Née), and tanoak (*Lithocarpus densiflorus* [Hook. & Arn.] Rehd.) constitute a huge reservoir of fuel and fiber that at present is not being effectively used. Other "products" such as wildlife habitat, watershed protection, and recreation-esthetic values may be more important than traditional wood products. Although little is known about the ecology and silviculture of California oaks, some knowledge is emerging. This paper attempts to summarize this knowledge and to touch briefly on wildlife, watershed, and esthetic considerations.

Of the 15 endemic oak species in California, 8—plus tanoak—grow to tree size and should be amenable to hardwood forest management. One or more species of oak can be found throughout the State. They occupy several major vegetation zones or types including chaparral, woodland, mixed evergreen, and mixed conifer. Oaks grow at elevations from near sea level to 10,000 feet (3050 m), and where the growing season ranges from about 90 to 350 days. California oaks total about 3 billion ft^3 (85 million m^3) net volume; California black oak and tanoak account for 72 percent of this volume. However, total oak volume is actually much larger because open-grown trees on noncommercial forest land are not included in these totals.

Most California oaks have adapted to harsh, semiarid, environments. Paleobotanists have traced these oaks and related communities back to the Miocene epoch of 12 to 26 million years ago. Oak persistence is a function of high adaptability. Thus, it is no surprise that native oaks have a wide climatic amplitude and a rapid and dynamic response to gross disturbance such as fire. Oak species differ widely in their response to fire, however; bark thickness, amount of living and dead bark, and ability to sprout from the bole all affect the probability that an oak species will grow in an area of frequent fires. Sprouting from the root crown is the most important survival adaptation of most oak species, and helps to maintain established stands.

For the silviculturist, there is evidence that dense 60-year-old stands respond to thinning. On a good site in the northern Sierra Nevada, mixed stands of California black oak, tanoak, and Pacific madrone (*Arbutus menziesii* Pursh) produce up to 93 ft^3 of new growth per acre per year net (6.5 m^3/ha/yr) for the first 6 years after thinning. Leaving 102 to 125 ft^2 of basal area per acre (23 to 29 m^2/ha) seems to balance available resources with amount of growing stock, and if sustained, is a much better growth rate than that of unmanaged stands.

With management, stands of thrifty oaks should yield more wood, acorns, and water than similar unmanaged stands, at no cost and probably even at a gain in esthetic value. Recognition of these values could mean that native oaks are soon going to contribute to increased productivity from California forests.

Natural regeneration of oaks, in addition to root-crown sprouting, includes seedling establishment. Acorns, disseminated by rodents, birds, and other animals, enable oaks to occupy new areas; however, regeneration from acorns is often poor especially for blue and valley oaks (*Q. lobata* Née) for reasons as yet unclear. For tanoak and California black oak, regeneration from acorns can be skimpy or abundant, depending on a host of environmental factors and the voracity of wildlife.

The plant propagator can gather acorns before they mature, thus getting the jump on natural consumers. Early-picked acorns can germinate successfully if the tips of the acorn shells are first removed. Positioning the acorn point up, rather than point down or sideways, also speeds up germination and results in an increase in number of acorns germinating. Optimum acorn storage schedules are not yet known, but temperatures just above freezing and moisture contents near 60 percent of fresh weight appear best for scrub oak (*Q. dumosa* Nutt.) acorns picked in September.

Young-growth California black oak and tanoak stumps sprout vigorously after cutting. Sprouts grow rapidly; those of California black oak on good sites may be over 19 feet (6 m) tall after 10 years. With such a growth rate, they are strong competitors with shrubs and other trees. Thinning sprouts at age 4 has been suggested, but tests show it results in no measurable gain in height growth.

Vegetative propagation of oaks has not been used because of the difficulty in rooting most oak species. Successful use of tissue culture techniques has not been achieved either, although recent work with bud culture may have opened the way to practical clonal oak propagation.

Under natural conditions, fire is necessary for the perpetuation of oak woodlands, especially on sites where oaks compete with faster growing conifers. Low intensity prescribed fire may have a place as a management tool in established oak stands. Periodic burning would reduce the fuel accumulations that support high intensity wildfires which kill or severely damage tree trunks and crowns. However, even prescribed fire must be used with caution because every fire will cause some tree damage.

Figure 1—This 110-foot tall, 24-inch-diameter California black oak in Butte County is suitable for manufacture into several valuable wood products.

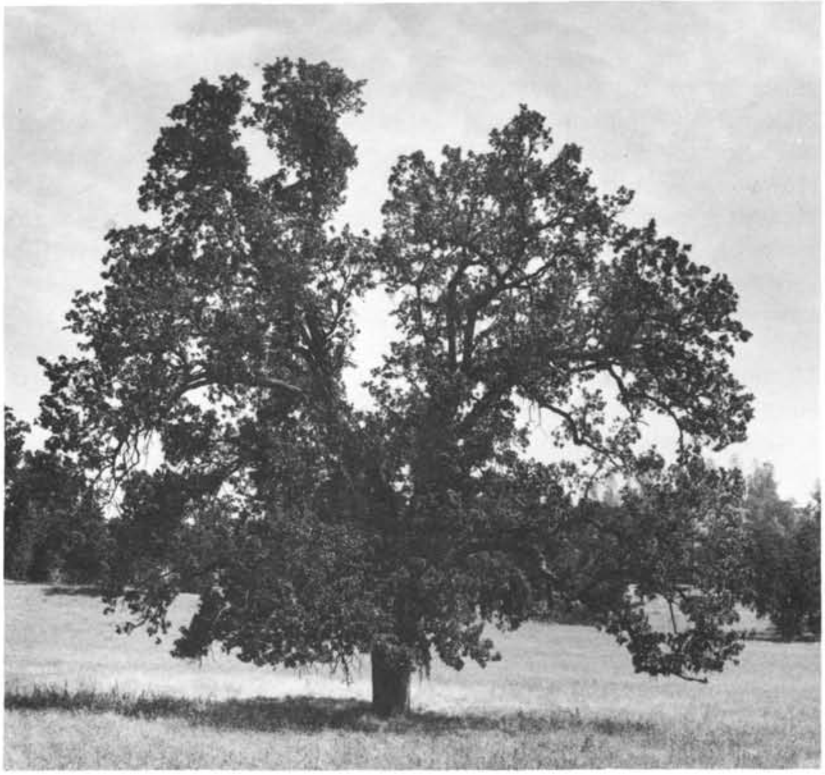

Figure 2—An open, spreading crown and large, crooked branches are typical of many California oaks.

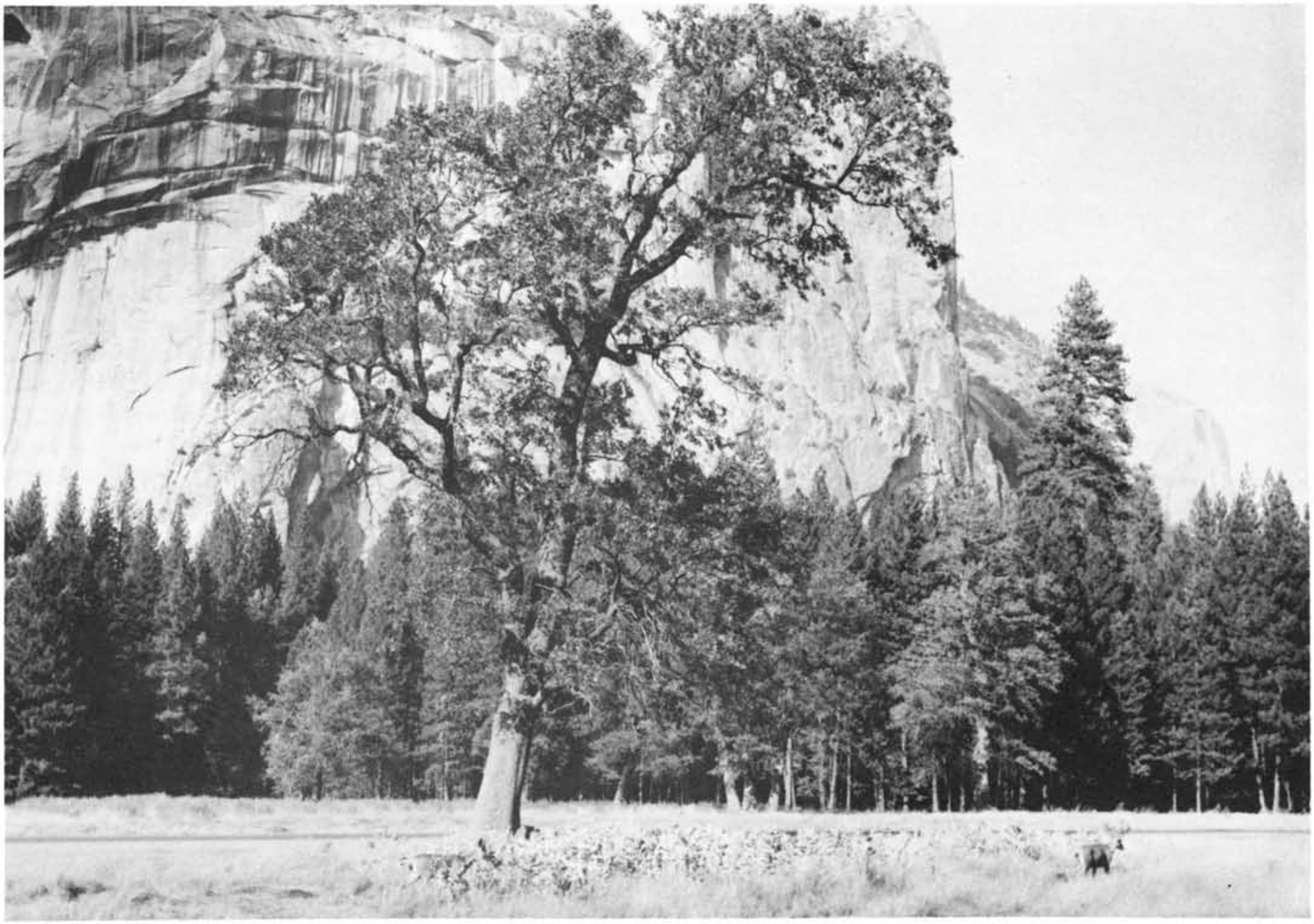

Figure 3—Acorns and foliage from California black oak are food much sought after by deer.

One of California's most valuable natural resources—its extensive oak forests and woodlands—has long been neglected and mistreated. Often, the oaks have been the target of eradication efforts aimed at enhancing other resource values. Interest in the ecology, management, and perpetuation of oak woodlands has increased dramatically in the last few years. Although in the past, oak has not been totally ignored by the scientific community, most forest managers would agree that guides for oak management are based on inadequate data.

This report presents available information for the management of the entire oak resource in California. Oak stands can be managed for many commodities and amenities. Hardwood trees of good form *(fig. 1)* can be manufactured into such valuable products as lumber, furniture, cabinets, and paneling. Trees of poor form *(fig. 2)* can now be cut into lumber for pallets and small specialty items. Small trees, plus thinnings from managed stands and residue from sawmills, are a potential source of energy. Twigs, leaves, and acorns provide food for a variety of wildlife and in many instances, are critical to their survival *(fig. 3)*. Domestic animals also use oaks as food. And, although not recognized widely, acorns are a potential energy-rich food source for humans as well. Because deciduous hardwoods do not intercept rain and snow to the extent that conifers do, less moisture evaporates from them. For example, water savings of up to 32 percent of annual precipitation have been realized from hardwood stands as compared to conifer stands (Urie 1977). Among all the values for which oaks are managed, that of providing scenic beauty cannot be ignored *(fig. 4)*.

Much that is known about California oaks has been available only in unpublished reports, dissertations, or case histories. A recent symposium has placed a considerable portion of this material in the literature (Plumb 1980). Here we present in summary form the ecological and silvicultural information which appears most useful for oak management in California.[1]

[1] This report is an expansion and updating of a paper submitted to the Symposium on Establishment and Treatment of High Quality Hardwood Stands in Temperate Climate Regions, Nancy, France, September 11-15, 1978 (Plumb and McDonald 1978).

Figure 4—Oaks like this old California black oak monarch in Mariposa County provide scenic views for the traveler.

SPECIES AND STANDS

To understand the oak resource and its management, we must first take a good look at the oaks themselves—the species and the broad groupings that reflect their similarities and differences. Then we need to know where they are and in what quantities, on the basis of the specific inventory data available.

Description

Eight native California oak *(Quercus)* species and one tanoak *(Lithocarpus)* grow to tree size *(table 1)*. Seven other species are shrubby and have low management potential. Most of the tree species have shrubby forms or varieties, such as California black oak *(Q. kelloggii* forma *cibata)*, shrub tanoak *(L. densiflorus* var. *echinoides)*, and shrub Oregon white oak *(Q. garryana* var. *breweri)*. A number of hybrids have been identified, also. Only 3 of the 15 *Quercus* species are classified as black oaks; 8 are white oaks, and 4 are in an intermediate class.

The genus *Lithocarpus* Blume., of which tanoak is a member, is made up of species intermediate between the chinkapins (*Castanopsis* Spach.) and the true oaks (*Quercus* L.). Although the foliage, twigs, and catkins are similar to the chinkapins, the acorns and acorn cups resemble the true oaks. Also, in weight, specific gravity, and hardness, tanoak is similar to oaks. For these reasons, and because tanoak is often an associate in oak communities, it is included here.

In addition to differing in leaf habit (*table* 1), evergreen and deciduous oaks also differ in size and form. Valley oak (*Q. lobata* Née) is the monarch of California oaks. In the mature tree, a massive trunk and great spreading branches support a regal crown. In contrast are the dense groves of evenly spaced, rather small individuals of interior live oak (*Q. wislizenii* A. DC.). The stately tanoak (*Lithocarpus densiflorus* [Hook. & Arn.] Rehd.) has a long, clear, gently tapering bole and an excurrent branching habit like that of conifers. California black oak (*Q. kelloggii* Newb.) typically has a long, clear bole free of branches, especially when growing in dense stands. Both tanoak and California black oak are often found as single trees or groves within the conifer forest. They also occupy more extensive areas, particularly if some disturbance has killed the conifers.

Table 1—*Prominent oaks (*Quercus *species and tanoak) native to California*

Growth habit[1] and common name	Species name	Subgroup	Distribution as percent of State area[2]
Trees:			
California black (D)	*Q. kelloggii*	Black	18.4
Blue (D)	*Q. douglasii*	White	17.5
Interior live	*Q. wislizenii*	Black	16.0
Coast live	*Q. agrifolia*	Black	15.2
Canyon live	*Q. chrysolepis*	Intermediate	12.7
Valley (D)	*Q. lobata*	White	5.8
Oregon white (D)	*Q. garryana*	White	5.5
Engelmann	*Q. engelmannii*	White	1.2
Tanoak	*Lithocarpus densiflorus*	—	7.8
Shrubs to small trees:			
Scrub	*Q. dumosa*	White	—[3]
Leather	*Q. durata*	White	—
Dunn	*Q. dunnii*	Intermediate	—
Sadler	*Q. sadleriana*	White	—
Island	*Q. tomentella*	Intermediate	—
Desert scrub	*Q. turbinella* ssp. *californica*	White	—
Huckleberry	*Q. vaccinifolia*	Intermediate	—

[1]Evergreen except deciduous (D) as noted.

[2]Based on maps by Griffin and Critchfield (1972).

[3]No estimate available.

Oregon white oak (*Q. garryana* Dougl. ex Hook.) can be startling in appearance when its white bark stands out among other trees. Coast live oak (*Q. agrifolia* Née), in contrast, has dark gray bark, and is unique in its branch habit, forming large horizontal branches near the ground. Engelmann oak (*Q. engelmannii* Greene) grows in association with coast live oak and has the same general appearance, but with lighter green leaves which are semipersistent. Canyon live oak (*Q. chrysolepis* Liebm.) often is identified by its large acorns and cups.

Distribution

Lack of knowledge of exact distribution and volume of California oaks is a major problem facing resource managers. Oaks are found on 15 to 20 million acres (6 to 8 million ha) in California (*fig. 5*). Together, these oaks occupy a rather wide range of elevation that increases from north to south. The relative distribution (percent of total State area) of tree-sized species is given in *table 1*. These values are not cumulative—some species overlap in area.

Oaks occupy a wide variety of soils, the one consistent exception being those soils which are poorly drained. Well-drained soils with textures ranging from fine-grained to cobbly or gravelly, sandy loams, or even skeletal soils of poor development, support oaks. Rather wide ranges of soil pH and structure also characterize soils within the natural ranges of oaks. Moderately acid to mildly alkaline soils (pH 5.6 to 7.5), and soil structures ranging from granular to angular-blocky are common. Soil depth under oaks commonly ranges from 20 to 40 inches (50 to 100 cm), and average annual temperature at the 20-inch depth ranges from 47 to 70° F (8 to 21° C). Thus, oaks are more commonly found on warm than on cold soils.[2]

Oak species are an important component of at least four vegetation types—woodland (subdivided into northern, southern, and foothill), mixed conifer, mixed evergreen, and chaparral.

The foothill woodland surrounds California's central valley and the lower elevations of the Coast Range, forming a transitional zone between the valley grasslands and the mixed-conifer forest at higher elevations. Blue oak (*Q. douglasii* Hook. & Arn.) and valley oak are the primary oak species, with a component of interior live oak. In southern California, coast live oak, and Engelmann oak to a limited extent, replace blue oak and valley oak. To the north, the northern oak woodland of mostly Oregon white oak occupies the warmer, drier slopes within the mixed-conifer forest.

The mixed-conifer forest occupies the middle elevation regions of the Cascade and Sierra Nevada Mountains with some distribution in the Transverse Ranges of southern California. California black oak is common in this forest type along with canyon live oak, which is often found on steep, rocky hillsides.

The mixed-evergreen forest extends from the Coast Ranges of central California northward to southern Oregon. In the North Coast Range, it is east of the redwood forest. Tanoak and Pacific madrone are prominent hardwoods, along with Oregon white oak, canyon live oak, and California black oak. To a limited extent, the mixed-evergreen forest also is found in the lower portion of the mixed-conifer forest in the northern Sierra Nevada.

Chaparral is a complex mixture of several evergreen shrubs. It is found on the dry, rocky slopes of the Peninsular Ranges in southern California and throughout the Central Valley foothills below the mixed-conifer forest. Scrub oak (*Q. dumosa* Nutt.) is an important component of chaparral, along with interior live oak at higher elevations and on the more moist sites. Both of these oaks, plus canyon live oak and coast live oak, tend to form a riparian woodland along the canyon bottoms and dry washes in southern California. Huckleberry oak (*Q. vaccinifolia* Kell.) is a common component of the montane chaparral of the Sierra Nevada, Klamath, and North Coast Mountains.

Inventory

California's oak resource is estimated at about 3 billion ft^3 (85 million m^3) net volume.[3] However, the total growing stock volume probably is greater than this because much of it is in open-grown savanna-type trees not normally included in volume estimates (*fig. 6*). California black oak and tanoak account for about 2.2 billion ft^3 (62 million m^3), or about 72 percent of the reported volume (*fig. 7*). The average annual growth, as a gain in volume, of the nine tree species referred to earlier was about 66 million ft^3 (1.9 million m^3) in 1975.

Data on volume and yield are scarce. Local volume tables are available for California black oak, Pacific madrone, and tanoak (McDonald 1978). These tables provide information on bark thickness, height, diameter, volume, and crown relationships. Stand volume and weight tables are also available for the Central Coast woodland oak species (Pillsbury and Stephens 1978). The tables are for the open-grown, uniformly dense, branchy tree forms typical of coast live oak, interior live oak, and blue oak in that area. Volume tables have recently been developed for valley oak.[4]

[2]Mallory, James I. 1979. Personal communication. Soil-Veg. Surv., Calif. Dep. For., Redding, Calif.

[3]Bolsinger, Charles L. 1978. Personal communication. Forest Serv., U.S. Dep. Agric., Portland, Oreg.

[4]Pillsbury, Norman. 1978. Personal communication. Calif. Polytech. State Univ., San Luis Obispo.

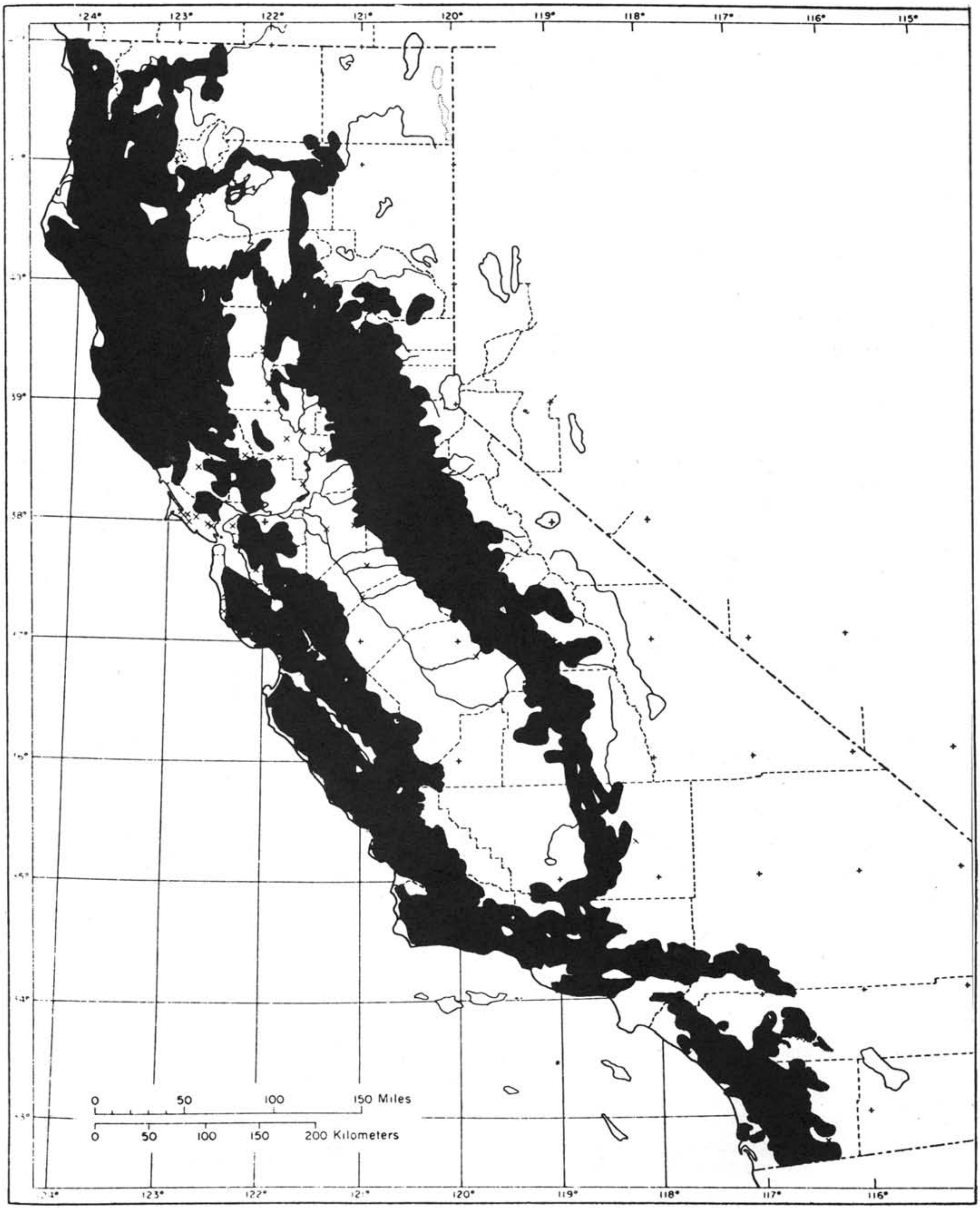

Figure 5—Combined distribution of tanoak (*Lithocarpus densiflorus*) and eight oaks (*Quercus* spp.) reaching tree size is shown in this map (after Griffin and Critchfield 1972).

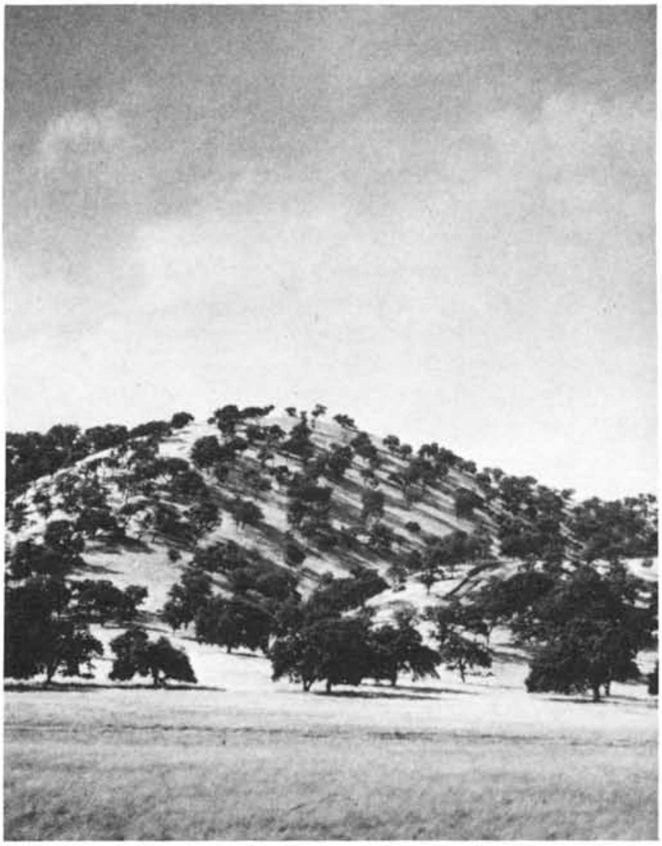

Figure 6—Several million acres of oak woodland are composed of open-grown trees with branchy, wide-spreading crowns.

Figure 7—Much of California's oak resource is in young-growth similar to this black oak stand in Shasta County.

OAK GEOGRAPHY AND ECOLOGY

The presence of the extensive oak stands distributed throughout California today is the result of millions of years of evolutionary development—development influenced primarily by climatic conditions, but in which fire has also played an important role.

Evolutionary Development

To understand the response of oak species to manipulation, we must consider their paleobotanical evolution. Four of the oak species in California today can be traced directly to the Mascall Flora of the Miocene period of 12 to 26 million years ago. One fossil species, *Q. convexa*, may be a common parent for the modern-day true evergreen oaks (Chaney 1925). Blue oak apparently had a Miocene ancestor as well (Axelrod 1950).

These oaks have survived catastrophic vulcanism, glaciation, upheaval, and subsidence in at least part of their present range. Some species and their vegetative associates not only have been evolving and adapting for millennia, but have done so as components of communities which are largely intact today. The tanoak-Pacific madrone-California black oak complex of the mixed-evergreen forest of northwestern and north-central California is an example of this development.

Animals are part of this community as well. Those which disseminate acorns could well have been the means by which the oaks survived the catastrophic geological events of the past. "It is not extravagance, but good investment, for the oaks to provide subsistence for a continuing population of animal associates" (Grinnell 1936).

Climatic Influence

Oaks, either as individual species or as community associates, readily adapt to climatic extremes (*table 2*). In most of California, rain falls mainly during late autumn, winter, and early spring, with very little from June through August. Except along the immediate coast, mean maximum and minimum temperatures vary greatly between summer and winter. Many oaks grow a little during mild winter weather.

Table 2—*Climatic variables affecting major vegetation types that include native California oaks*[1]

Vegetation type	Average annual rainfall	Average annual temperatures		Frost-free days
		Max. summer	Min. winter	
	Inches	*°F*		
Woodland:				
Northern	25 to 40	80 to 94	31 to 38	180 to 265
Foothill	15 to 40	75 to 96	29 to 42	175 to 310
Southern	15 to 25	84 to 92	32 to 44	200 to 350
Mixed conifer[2]	25 to 80	80 to 93	22 to 34	90 to 210
Mixed evergreen	25 to 65	75 to 95	29 to 39	200 to 300
Chaparral	14 to 25	82 to 94	29 to 45	250 to 360

[1]Source: Munz and Keck (1959).
[2]Values are for the Yellow Pine Forest community.

The climatic range of some of the vegetation types overlap, and thus several species are common to more than one type. In general, each oak is found where moisture and temperature combine to meet its particular environmental requirements, regardless of vegetation type.

Fire Influence

Because of the long, hot, dry California summers, fire hazard is high. During the past several million years, fire has had an important influence on the current distribution of oak vegetation. Fire often eliminates the oak's chief competitors—conifers—and influences oak species composition, density, and form. Though beneficial in a long-term sense, fire does, of course, kill oak trees: "Any fire damages a stand of California black oak" (Edwards 1957). Crown fires kill trees of all ages and ground fires, if not fatal, injure the bole, and thus facilitate entry of insects and disease. Even if the bark is 1 to 3 inches (2.5 to 7.6 cm) thick, as for tanoak, some trees are badly injured. Indeed, "fire is the principal enemy of individual tanoak trees" (Roy 1957).

Plants have adapted to fire by several mechanisms, including (1) the continual production of dormant buds, protected by bark or soil, which begin active growth after injury to the stem or crown; (2) heat-induced flowering; (3) heat-induced release of seed held on the plant; and (4) heat-induced germination of dormant seed (Gill 1977). Sprouting of dormant buds is the most important survival mechanism of oaks (*fig. 8*).

Another adaptation is the low sensitivity of certain oak species to fire. Coast live oak is tolerant of fire and may sprout from the main trunk and upper branches after being charred completely (*fig. 9*). It has thick, live, inner bark and practically no dead outer bark. Most other oak species are more sensitive to fire. Canyon live oak may be damaged by a low-intensity ground fire (*fig. 10*). It has a flammable, flaky outer bark that contributes to its destruction. Because it often grows in rocky areas, however, where ground cover is sparse, it tends to escape serious fire damage.

If burning occurs too often, sprouting, either from bole or root crown, can be of limited value in preserving oak trees. The minimum "safe" interval between fires, however, has not yet been determined. Usually, at least some of the oaks in a stand will be killed in every fire. The shorter the span between successive fires, the greater the number of trees killed in a given length of time. Sufficient time must elapse between fires for the trees to recuperate and for reproduction to become established. It can be assumed that if fires occur at frequent intervals, some oak species may be replaced by vegetation with a shorter natural rotation age, like grass, or by species having a widely disseminated seed source, like some woody shrubs (Wells 1962).

Whether aboriginal man used fire as a tool before European settlement is not clear (Griffin 1976). Although the Indians unquestionably used fire for various pur-

Figure 8—Most oak species vigorously sprout from the base or root crown after topkill by fire.

Figure 9—Coast live oak trees will sprout along the main trunk and upper crown even though severely burned (sprouts are 2 to 3 feet long within 2 years after burning).

poses, they probably burned less area than is often suggested (Burcham 1959). Evidence of the ecological effect of fire has been obscured in the last 200 years by "civilized" man, who not only sets fires but also attempts to exclude them, though with questionable success.

OAK MANAGEMENT

If the maximum amount of goods and services is to be obtained from a natural resource like the oak stands and woodlands, they must be managed for a specific product or group of compatible products. Nature cannot be allowed to take its own random course. Successful management thus implies considerable knowledge of the system being managed so that appropriate, positive actions are taken.

Use of traditional silvicultural techniques in California's oak stands is rare. In fact, rough guidelines for managing California black oak in California's National Forests are only now being developed, although one private timber company in northwestern California is managing tanoak on a nonintensive basis. Even-aged silviculture is recommended if production of high quality sawtimber and veneer is the primary management objective. Present knowledge suggests that this goal is probably best achieved through clearcutting or possibly a form of shelterwood cutting. Modifications of silvicultural techniques will be needed when management for other resources or combinations of resources is performed.

Silvicultural research on California oaks is in its infancy. Bibliographies on California black oak (McDonald and Sundahl 1967) and tanoak (McDonald 1977) are available, however. A study on the silviculture-ecology of California black oak, tanoak, and Pacific madrone on good sites is aimed at regenerating these species, quantifying sprout dynamics, determining stand growth and yield, and gaining a better understanding of their ecology (McDonald 1978).

Annual volume growth from a stand thinned to different basal areas is shown in *table 3*. The original stand was a mixture of 60-year-old California black oak, tanoak, and Pacific madrone, with an average basal area of 198 ft^2/acre (46 m^2/ha), and an average of 659 stems per acre (1628/ha) greater than 2 inches (5 cm) d.b.h. The stands were thinned to six different basal areas ranging from 85 to 141 ft^2 of basal area per acre (19 to 32 m^2/ha). Thinned stems to a 2-inch (5-cm) top were used in a commercial firewood operation. After 6 years, greatest growth had occurred on plots thinned to basal areas of 102 and 125 ft^2 per acre (23 and 29 m^2/ha). Mortality appeared to be related to species and plot density. At densities above 125 ft^2 per acre, the too-shady environment was adverse to California black oak; at densities below 102 ft^2, which resulted in an environment that was brighter and hotter, mortality was greatest for

Table 3—*Volume growth for California black oak, tanoak, and Pacific madrone, by different residual basal area levels, for 6-year period, Yuba County, California*

Item	Growth on plots thinned to residual basal area level (ft^2/acre) of ...						Growth on control plot (basal area
	85	102	110	125	136	141	209 ft^2/acre)
	Ft^3/acre/yr						
Gross annual growth	70.4	87.5	80.7	93.3	73.3	81.7	93.0
Mortality	22.7	0.0	8.4	0.0	20.0	7.8	21.1
Net annual growth	47.7	87.5	72.3	93.3	53.3	73.9	71.9

Figure 10—Canyon live oak is sensitive to even a light ground fire which often completely girdles the tree.

tanoak and Pacific madrone. Too little time has elapsed to justify projection of these preliminary results; nevertheless, results so far are encouraging. More than one-third of the original stand has been harvested, while a rate of growth much greater than that of the uncut stand has been maintained.

Other examples of oak management are less oriented to wood and fiber production. In southern California, the concern of a large human population for environmental quality is a major force. Often, when a large tract of land is to be developed, environmental impact reports must be prepared and efforts made to save the native trees. Consulting firms in private forestry contribute to this process, considering the effects of road and home construction, cutting and filling of earth, damage to roots, runoff from streets, and increased susceptibility to disease and other agents.

To assess the above effects, urban foresters are beginning to gather basic data on root distribution and pattern, incidence of disease, and response of oaks to a kind of manipulation different from that which is commodity oriented. Thus, lessons learned in the city may someday apply to the forest.

Stand Regeneration

Methods of regenerating native California oaks for a variety of purposes, mostly horticultural, have probably received more consideration than most other aspects of oak management. Native oak seedlings currently are grown almost exclusively in commercial horticultural nurseries. Large seedlings, several years old, form the bulk of the outplanted material. Few native oak seedlings, if any, are grown in forest nurseries, and no instances of regenerating oak as a regular forest operation are known.

Natural regeneration consists of seedlings and root-crown sprouts. In mixed-evergreen and mixed-conifer forests, both forms of regeneration usually are present. Numbers per acre range from a very few to several thousand, depending on number of stumps, availability of seed, kind of seedbed, seed consumers, and many other factors. In the woodlands, however, natural regeneration often is lacking (Griffin 1976, White 1966). Why regeneration is so poor is not known, although many reasons have been suggested, including an abundance of herbivores, frequent fires, and replacement of native perennial grasses by possibly more competitive annual grasses.

Seedlings

Acorn crops vary in size from year to year and from tree to tree. Accurate records have not been kept for most California oaks, but many species seem to have a 2- or 3-year interval between heavy crops. This pattern is true for valley oak (Griffin 1976). In one study area in the Santa Lucia Mountains, Griffin tallied an average of 9.1 acorns per ft^2 ($98/m^2$) for four trees in one year, followed by subsequent annual crops of 0.6, 2.8, 0.1, and 6.0 acorns per ft^2.

A large crop of acorns early in the growing season does not guarantee a large crop of acorns at maturity. In a study near Lake Arrowhead, 153 acorns on small branches of a canyon live oak were numbered and their condition was periodically rated as follows:

	July 13	August 24
Acorns:	*Percent*	
Healthy	80	23
Undeveloped	8	10
With insects	8	20
Missing (only cups present)	4	47

As the acorns would not mature for at least 1½ to 2 more months, by then even fewer healthy acorns could be expected to remain. Wildlife may also reduce an immature acorn crop on the tree. For example, during late September (from 1971 to 1974), squirrels harvested all of the acorns from several scrub oak trees being studied.

Acorns of most species germinate freely, but seedling survival longer than a few years is difficult for valley oak and blue oak. In the Santa Lucia study, 550 seedlings were tagged between 1970 and 1973; by 1974, no living seedlings were found (Griffin 1976). They were eaten by deer, birds, insects, squirrels, and cattle. Pocket gophers are known to eat both the shoots and the roots and may kill young trees up to age 6.

Because mature scrub oak acorns were rarely found on the ground, tests were run to determine how early in the growing season viable acorns could be picked. Acorns were collected five times at 2-week intervals. The tips of the acorn shells were either left intact or removed at seeding time. Results (for 15 to 40 acorns per treatment per collection date) are as follows:

	Percent germination when collected on...					
	Aug. 17	Aug. 31	Sept. 14	Sept. 28	Oct. 12	Average
Treatment:						
Intact acorns	15	4	0	20	90	26
Tips removed	50	89	86	100	95	84

Viable acorns could be picked as early as August 17, but successful germination depended on removing the tip of the acorn shell at the time of seeding. Detipped acorns germinated sooner than those left intact. Percent of acorns germinating increased for both treatments as the season progressed and by October 12, germination of intact acorns was almost as high as for the detipped ones and emergence was just as rapid.

The position of the acorn in the ground affects germination. In a large field test, 840 tanoak acorns were seeded point up, 722 point down. A cumulative record of new seedlings indicated the importance of acorn position:

	Seedlings recorded on...						
	Apr. 19	May 18	June 8	June 28	July 18	Aug. 28	Sept. 18
Acorns seeded:							
Point up	317	415	436	440	445	—	—
Point down	9	70	110	140	157	163	165

Maximum germination thus was achieved by July 18 for the acorns placed point up, but not until September 18 for those placed point down. Almost three times as many seedlings originated from acorns placed point up.

Acorns of the white oaks generally do not store well, and storage is even less satisfactory when the acorns are picked before maturity and stored without partial drying. Acorns germinate and develop gradually when stored in a plastic bag at 35°F (2°C), eventually becoming a twisted mass of moldy roots and partially developed shoots.

Reducing acorn fresh weight lengthens their storage period. Several tests with scrub oak acorns picked in mid-September have shown that they would not germinate in cold storage after air drying to 60 percent of their initial fresh weight (IFW) (*table 4*). These acorns remained viable for 8 months, and some were still viable after 15 months.

The effect of drying on acorn viability is complicated because acorns picked prematurely have a higher moisture content than those picked when mature. Thus,

Table 4— *Germination of scrub oak acorns (based on 10 acorns per treatment) picked in mid-September and dried to different moisture contents*

Moisture content[1]	Germination during and after storage period (months)								
	0	2		4		6		8	
		During	After	During	After	During	After	During	After
	Percent								
100	90	84	100	100	100	100	100	100	—[2]
80	90	7	100	58	100	90	100	—[2]	—[2]
60	—[3]	0	80	0	100	0	70	0	90
40	0	0	0	0	0	0	0	0	0

[1]Percent of initial fresh weight.
[2]Frozen during storage.
[3]No available data.

acorns picked in mid-August remained viable when dried to 40 percent of their IFW; those picked in mid-September were killed when dried below 50 percent IFW.

Sprouts

Both young-growth California black oak and tanoak stumps sprout vigorously after cutting and produce dense clumps of competing stems. The number of sprouts per stump varies with the cutting method. Forty-nine California black oak sprouting stumps were studied in stands on a good site; stands had been clearcut, or cut to shelterwood standards with 50 percent of the basal area removed. The number of sprouts per stump was initially half as numerous in the shelterwood as in the clearcutting. After 10 years (*table 5*), sprouts were only slightly fewer in the shelterwood.

To determine competition among individual sprouts on each stump, 20 sprouting California black oak stumps in the clearcutting were thinned to four sprouts per stump. Both thinned and unthinned sprouts were compared in height to unthinned sprouts in the shelterwood (*table 5*).

The inhibiting effect of the shelterwood trees is reflected in sprout height as it previously was in sprout number. On the clearcut site, thinned clumps did not differ significantly in height growth from unthinned clumps. As the dominant sprouts of unthinned clumps apparently capture a maximum amount of available resources, thinning California black oak sprout clumps does not appear to be profitable.

Vegetative Propagation

Oak cuttings are generally difficult to root. However, more than 80 percent rooting of shrub turbinella oak (*Q. turbinella* Greene) "softwood" cuttings was obtained in Arizona from 3-year-old greenhouse-grown plants by Davis (1970). He controlled the temperature of both the mist chamber and the rooting medium independently. Based on seedling root growth studies, he found 86°F (30°C) to be the best temperature for the rooting medium, and about 10°F cooler for the air above.

Using a total of 430 stem cuttings from actively growing or dormant 1- and 2-year-old scrub oak seedlings, up to 40 percent rooting was obtained under intermittent mist and a rooting medium temperature of around 75°F (24°C). Ten weeks after cutting, rooting of sections from actively growing shoot terminal sections was twice that of dormant terminal sections.

The use of tissue culture techniques to propagate scrub oak was attempted in 1971 using buds, meristems, and other tissue. Several factors were evaluated including solid versus liquid media, light versus darkness, and various levels of growth regulators. Although callus tissue developed in many of the tests, differences between treatments were not obvious, and none were effective in producing differentiated tissue (roots or shoots). One notable exception was the development of 0.5- to 1.0-inch (1- to 2-cm) long "roots" from a few cultures in one test. This result, however, could not be verified. Successful use of oak buds to produce rooted, entire plants was recently reported;[5] clonal propagation of oaks may soon be practical.

Fire as a Management Tool

Although fire is anathema to individual oak trees, it is essential for continuation of oak stands under natural conditions, especially on commercial timber sites where the inherently taller conifers are more competitive. By destroying the conifers, the oaks are free to sprout. Because of rapid sprout growth, the oaks capture the area and are perpetuated.

[5]McCown, Brent H. Presented at the workshop on seedling physiology and growth problems in oak planting, Columbia, Mo., Nov. 6-7, 1979.

Table 5—*Average number of California black oak sprouts per stump and sprout height for 10 years on the Challenge Experimental Forest, Yuba County, California*

Years after cutting	Sprouts per stump		Height of sprouts		
			Clearcut		Shelterwood (Unthinned)
	Clearcut	Shelterwood	Thinned	Unthinned	
			Feet		
0	55+	28	—[1]	—	2.0
2	55+	23	—	—	2.9
4	35	17	7.5	7.9	3.9
6	23	15	12.5	12.1	4.9
8	18	13	16.1	16.1	5.9
10	15	12	19.3	19.7	7.0

[1]No available data.

Fire is also an almost inescapable occurrence in established California woodlands; attempting to exclude it is not practical. Although a policy of fire exclusion may permit development of large trees whose trunks and upper crowns resist fire damage, periodic low-intensity fires should reduce fuel loading and prevent high intensity fires that kill the trees. Thus, fire used as a management tool could eliminate vegetative competition and reduce heavy fuel accumulations on the ground. This is especially feasible where trees are valued primarily for recreation, wildlife, or values other than wood products and a small amount of injury from fire may be of minor importance. For example, prescribed fire might be used to manage coast live oak which is resistant to fire injury. However, unless protected, seedlings and small trees would be damaged, and acorn production reduced if crowns are damaged.

The effect of fire on tree disease has had little attention other than as fire wounds providing ports of entry for pathogens (Parmeter 1977).

FUTURE DIRECTIONS

Forest landowners in California seem to have adopted a "wait and see" attitude toward management of their oak stands. Plainly, those stands having poor form and slow growth are, for the foreseeable future, best suited for development of nontimber values. But stands having good form and good growth have potential timber values.

An expanding population and accelerated demands for wood products, fuel, and fiber create a growing interest in the management of oak stands. Only through increased interest, and in turn increased management, will California's oak resource make a full contribution to the productivity of California forests.

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Native oak species grow on 15 to 20 million acres (6 to 8 million ha) of California land, and have an estimated net volume of about 3 billion ft^3 (85 million m^3). This resource, valuable not only for traditional wood products, but also for wildlife habitat, watershed protection, and recreational-esthetic values, is not effectively managed, partly because of a lack of silvicultural and other management knowledge. Some helpful information is available. Viable acorns of scrub oak *(Quercus dumosa Nutt.)* can be picked 1½ to 2 months before normal maturity, and after proper drying, can be stored for at least 1 year at 3 to 4° C. Mixed stands of California black oak *(Q. kelloggii Newb.),* tanoak *(Lithocarpus densiflorus* [Hook. & Arn.] Rehd.), and madrone *(Arbutus menziesii* Pursh) increased growth when thinned to 102 to 125 ft^2 of basal area (23 to 29 m^2/ha). But, thinning sprouts of individual California black oak stumps did not enhance growth of the remaining sprouts. Fire can be a management tool for some species, such as coast live oak, *Q. agrifolia Née,* which is fire tolerant.

Retrieval Terms: Quercus spp., *Lithocarpus densiflorus,* California, timber management, silviculture, fire effects