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Oak Forest Ecosystems

Ecology and Management for Wildlife

EDITED BY
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AND
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Contents

Chapter 19

California's Oak Woodlands

RICHARD B. STANDIFORD

California's oak woodlands, also known as hardwood rangelands, cover 10 million acres, or 10% of the state (Bolsinger 1988, Greenwood et al. 1993, Pacific Meridian Resources 1994). These areas have an overstory tree canopy predominantly in the oak genus (*Quercus* spp.) and an understory of exotic annual grasses and forbs and occasional native perennial grasses (Griffin 1973, Bartolome 1987, Holmes 1990, and Allen et al. 1991).

Since European settlement of California, oak woodlands have been managed primarily for livestock production. These areas have taken on a new importance since the recognition that they have the richest species abundance of any habitat in the state, including more than 300 vertebrate species, 5,000 invertebrate species, and 2,000 plant species (Verner 1980, Barrett 1980, Garrison 1996). Oak woodlands also enhance the water quantity and quality, outdoor recreation, and aesthetic effect of the region. Over 80% of California's oak woodlands are in private ownership (Greenwood et al. 1993).

Oak Species and Classification

The five major oak species occurring in oak woodlands include three deciduous white oak species—blue oak (*Q. douglasii*), valley oak (*Q. lobata*), and Engelmann oak (*Q. engelmannii*)—and two evergreen oaks—coast live oak (*Q. agrifolia*) and interior live oak (*Q. wislizenii*). Three additional species are found in these oak woodlands, namely California black oak (*Q. kelloggii*), Oregon white oak (*Q. garryana*), and canyon live oak (*Q. chrysolepis*). However, these three are more typically found on moister, more productive conifer-dominated sites. Table 19.1 briefly describes the general characteristics the most important of these oak species.

Various systems have been used to classify oak woodlands in California. Table 19.2 provides a general cross-reference of these classification systems. The distribution, density, and abundance of the various oak species, together with other tree, brush, and herbaceous species, form the basis for evaluating the potential of a hardwood rangeland site for providing economic and ecological utility. Although there are numerous ways of classifying California's oak-dominated woodlands, the five vegetation types used in the California Wildlife Habitat Relationships System will be used in this discussion (Mayer and Laudenslayer 1988). These names for California oak woodlands are based on the dominant tree species and include valley oak woodland, blue oak woodland, blue oak–foothill pine woodland, coastal oak woodlands, and montane hardwood forest (Table 19.3).

Spatial and Temporal Aspects of Oak Woodland Sustainability

Landscape-Level Sustainability

Landscape factors affecting oak woodland distribution include long-term climatic factors and, more recently, human-caused events. Pollen analysis shows shifts in distribution of oak stands along altitudinal gradients (Byrne et al. 1991). Over the past 40 years, California's oak woodlands have decreased by over one million acres on a statewide scale (Bolsinger 1988) due to human-induced factors. Major losses from 1945 through 1973 were from rangeland clearing for enhancement of forage production. Major losses since 1973 have been from conversions to residential and industrial development. Regionally, some oak woodlands have decreased due to urban expansion (Doak 1989), firewood harvesting (Standiford et al. 1996), range improvement (Bolsinger 1988), and conversion to intensive agriculture (Mayer et al. 1985). The results have been habitat fragmentation, increased conflicts between people with different value systems, predator problems, and soil and water erosion.

Stand-Level Sustainability Considerations

From 1932 to 1992, blue oak woodland canopy density and basal area increased under typical livestock grazing and influenced by fire exclusion policies (Holzman 1993). This indicates that many oak stands were sta-

Table 19.1
General characteristics of California's important hardwood rangeland oak species

Characteristics	*Blue oak*	*Interior live oak*	*Coast live oak*	*Valley oak*
Scientific name	*Quercus douglasii* Hook. & Arn.	*Quercus wislizenii* A. DC.	*Quercus agrifolia* Nee	*Quercus lobata* Nee
Common names	blue, white, mountain, rock, iron, post, jack, Douglas	Interior live oak, highland live oak, Sierra live oak	Coast live oak, California live oak, encina	Valley, white, California white, mush, water, swamp, roble
Height	Usually 20–60 ft.; tallest > 90 ft.	Usually 30–75 ft.; shrub form 8–10 ft.	Usually 20–40 ft.; may reach 80 ft.	40–120 ft.
Mature tree dbh	Less than 1 ft., up to 2 ft.; largest > 6 ft.	1–3 ft.	1–4 ft.	1–4 ft.; largest > 8 ft.
Longevity	Long-lived, 175–450 yrs.	150–200 yrs.	Long-lived, 125–250 yrs.	Long-lived, 200–250 yrs.
Sprouting	Variable sprouter; not vigorous on dry sites	Very vigorous sprouter	Very vigorous sprouter	Not a vigorous sprouter
Acorn	Matures first year; variable in shape; warty scales; cup very shallow	Matures second year; very slender, pointed, 1 in. long; cup over half the nut	Matures first year; 3/4 to 2 3/4 in.; cup over 1/3 of nut and not warty	Matures first year; size variable but large and tapered; cup over 1/3 of nut, warty
Foliage	Deciduous; blue-gray color; smooth or slightly to deeply lobed edges; 1–3 in. long and 1/2– 2 in. wide	Evergreen; smooth to very spiny-toothed; dark green above and lighter below with waxy/shiny surface; 1–4 in.; flat	Evergreen 1–3 in.; roundish; dark and shiny above with gray or rusty fuzz underneath; cupped or spoon-shaped	Deciduous; leaves leathery with shiny, dark green-yellow above and grayish below; deep irregular lobes; 2–4 in.

Shade tolerance	Seedlings not tolerant	Somewhat shade tolerant	Shade tolerant throughout life	Seedlings somewhat tolerant; mature trees intolerant
Fire tolerance	Tolerates grass fires, not hot brush fires	Not very tolerant, but sprouts well after fire	Very tolerant of hot fires, due to thick bark	Not tolerant of fires
Elevation	500–2000 ft. in north; up to 5000 ft. in south	Below 2000 ft. in north; above 6200 ft. in south	Below 3000 ft. in north; up to 5000 ft. in south	500–800 ft. in north; up to 5600 ft. in south
Associates	Grades into open valley oak stands at low elevations, into denser live oak stands at higher elevation; foothill pine common	In pure stands or mixed with blue and/or coast live oak; valley oaks in south	Forms pure stands; also grows with interior live oak and coast live oak	Blue and Oregon white oak; sometimes interior live oak
Sites	Hot, dry sites with rocky soils, 12–40 in. deep; can't compete with live oak on better sites	Wide range, from valleys to foothills; moister areas than blue oak	Common on valley floors and not-too-dry fertile slopes	Prefers fertile, well-drained bottomland soils, stream-beds, and lower foothills
Notes	Confused with valley oaks when leaves are dusty	Confused with coast live oaks; distinguished by flat leaves	Confused with interior live oak but rounded and cupped leaves	Confused with Oregon white oak but acorns pointed with warty cups

Continued

Table 19.1 continued

Characteristics	*Engelmann oak*	*California black oak*	*Oregon white oak*	*Canyon live oak*
Scientific name	*Quercus engelmannii* Greene	*Quercus kelloggii* Newb.	*Quercus garryana* Dougl.	*Quercus chrysolepis* Liebm.
Common names	Engelmann, mesa	Black, California black oak	Garry oak, white oak, Oregon oak	Canyon live oak, canyon oak, gold cup oak, live maul, maul oak, white live oak
Height	20–50 ft.	60–90 ft.	50–80 ft.	60–80 ft.
Mature tree dbh	1–2 ft.	1–4 ft.	2–3 ft.; largest > 5 ft.	1–4 ft.; largest > 5 ft.
Longevity	100–200 yrs.	100– 200 yrs.; occasionally up to 500 yrs.	100–200 yrs.	Up to 300 yrs.
Sprouting	Variable sprouter	Excellent sprouter	Excellent sprouter	Variable sprouter
Acorn	Matures first year	Matures second year; 1 1/2 in. long; thin cup over half the nut	Matures first year; 1 in. long with shallow cup	1 1/2 in. long; thick, shallow cup
Foliage	Considered deciduous but foliage may persist during winter; similar to blue-gray color of blue oak	Deciduous; 5 in. long; 5–7 lobed; spiny leaf tips; dark yellow-green above and pale yellow-green below	Deciduous; 4–6 in. long; evenly and deeply lobed with rounded leaf tips; lustrous dark green and shiny above and pale green below	Evergreen; 3 in. long; persists 3 or 4 seasons on tree; usually not lobed; leathery

Shade tolerance	Seedlings tolerant, mature trees intolerant	Seedlings intermediately tolerant; mature trees intolerant	Seedlings intermediately tolerant; mature trees intolerant	Tolerant
Fire tolerance	Very tolerant of hot fires	Very sensitive to cambium being killed in hot fires	Maintained in open stands by regular, low-intensity fires	Sensitive to hot fires
Elevation	Under 4000 ft.	200–6000 ft.	500–3000 ft.	300–5000 ft.
Associates	In pure stands and with coast live oak	Most common with tanoak, madrone, mixed conifer forest species; also with coast live oak, interior live oak, and blue oak	Douglas-fir and mixed evergreen forests; Pacific madrone and tanoak	Mixed conifer, chaparral, and woodland species; tanoak, Douglas-fir, Pacific madrone, coast live oak
Sites	Warm, dry fans and foothills	More common on forest sites; found on moister hardwood rangelands; well-drained soils	Cool, humid sites near coast to hot, dry sites inland	Most widely distributed oak in state; sheltered north slopes and steep canyons
Notes	Very limited range in south makes protection a high priority	Protected by Forest Practice Act on timberlands; commercial properties for finished lumber	Protected by Forest Practice Act on timberlands	Both a shrubby and tree form; very dense wood

Table 19.2
Cross-reference for hardwood rangeland classifications in the Sierra Nevada

Allen et al. 1991	*CALVEG*[a]	*Griffin 1977*	*Munz and Keck 1973*	*Kuchler 1988*	*Eyre 1980*	*Mayer and Laudenslayer 1988*
Blue oak series	Blue oak	Foothill woodland–blue oak phase	Foothill woodland	Blue oak–digger pine	Blue oak–digger pine	Blue oak woodland
Blue oak series	Blue oak–digger pine	Foothill woodland–blue oak phase	Foothill woodland	Blue oak–digger pine	Blue oak–digger pine	Blue oak–digger pine
Interior live oak series	—	Interior live oak North slope phase	Foothill woodland	—	—	Montane hardwood
—	Canyon live oak	Blue oak phase, interior live oak phase	Foothill woodland	Sierran montane forest	Canyon live oak	Montane hardwood conifer, montane hardwood
Black oak series	Black oak	Black oak phase	Foothill woodland	Sierran montane forest	California black oak	Montane hardwood conifer, montane hardwood
Valley oak series	Valley oak	Valley oak phase	Foothill woodland	Valley oak savanna	—	Valley oak woodland
—	—	Riparian forest	—	Riparian forest	—	Valley foothill riparian
—	—	Northern oak woodland	Northern oak woodland	Oregon oak	Oregon white oak	Montane hardwood

[a]U.S. Forest Service and California Department of Forestry and Fire Protection Land Cover Mapping and Monitoring Program.

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Table 19.3
Acreage of California hardwood rangeland habitat types

Habitat type (CWHR)	*Central Coast*[a]	*San Joaquin Valley/ Eastside*[b]	*Sacramento Valley/ North Interior*[c]	*Central Sierra*[d]	*North Coast*[e]	*Southern California*[f]	*Total*
Blue oak woodland	1,096,990	1,078,080	945,170	365,920	75,900	34,000	3,596,060
Blue oak–foothill pine woodland	283,180	332,090	458,620	230,530	0	0	1,304,420
Valley oak woodland	54,600	16,870	1,760	0	2,230	1,000	76,450
Coastal oak woodlands	1,277,630	24,710	20,790	0	217,650	399,000	1,939,770
Montane hardwood	632,880	775,450	1,087,910	1,019,910	539,020	86,000	4,141,170
Total	3,345,270	2,227,200	2,514,240	1,616,360	834,800	520,000	11,057,870

Source: California Department of Forestry and Fire Protection database.
[a]Alameda, Contra Costa, Lake, Marin, Monterey, San Benito, San Luis Obispo, San Mateo, Santa Barbara, Santa Clara, Santa Cruz, Solano, Sonoma, and Ventura counties.
[b]Fresno, Kern, Kings, Madera, Merced, San Joaquin, Stanislaus, and Tulare counties.
[c]Butte, Colusa, Glenn, Lassen, Modoc, Plumas, Sacramento, Shasta, Sierra, Siskiyou, Solano, Sutter, Tehama, Trinity, Yolo, and Yuba counties.
[d]Amador, Calaveras, Eldorado, Mariposa, Nevada, Placer, and Tuolumne counties.
[e]Del Norte, Humboldt, and Mendocino counties.
[f]Imperial, Los Angeles, Orange, Riverside, San Diego, and San Bernardino counties.

ble or increased over a moderately long period, despite perceived natural regeneration problems (Muick and Bartolome 1987, Bolsinger 1988, Swiecki et al. 1997). However, more than 20% of the study sites were converted to other land uses, primarily residential subdivisions, during this period (Holzman 1993). A similar study of changes in total woody cover of blue oak–foothill pine woodland from 1940 to 1988 found these areas were relatively stable (Davis 1995).

Pollen analysis studies document the dynamics of oak woodland composition over a very long term and highlight the changing influence of human populations (Byrne et al. 1991). Oak woodlands were relatively stable during the long period of use by Native Americans. Beginning approximately 150 years ago with European settlement, introduction of livestock, and clearing for intensive agriculture, oak densities declined.

Exotic annuals first show up in the pollen record at that same time. After that initial exploitation of the oak resource in the early settlement period, since about 1850, oak cover has increased dramatically. Current oak densities, as determined from the pollen record, are at their highest level, due to fire exclusion policies of the last 50 years and the management practices associated with ranching that aim for low intensity but high extensivity.

Oak Woodland Ecosystem Processes

Since the introduction of domestic livestock and exotic annuals by European settlers, oak woodland ecosystems have changed dramatically. Herbaceous composition has changed from perennials to annuals (Holmes 1990). Fire intervals and intensity have increased (McClaren and Bartolome 1989b). Overstory cover, where not converted to another land use, has generally increased (Holzman and Allen-Diaz 1991). Soil moisture late in the growing season has decreased, and soil density has increased due to compaction from higher herbivore densities (Gordon et al. 1989). Riparian zones are now less dense and diverse (Tietje et al. 1991). (See Table 19.4.) These ecosystem process changes are discussed below.

Herbaceous Composition

The pre-European herbaceous community in oak woodland understory included native perennial bunchgrasses and forbs (Holmes 1990). Native species were displaced by alien annuals from Europe, Asia, Africa, and South America with the arrival of European settlers (Burcham 1970). Urbanization is accelerating the invasion of exotic plant species, although mitigation projects are under way that often require restoration of native grasses.

Grazing Processes and Forage Production

Livestock grazing has had a major impact on California's oak woodlands. By 1880, Spanish coastal missions had four million sheep and one million cattle (Holmes 1990), fostering a large demand for forage and oak browse. Currently, two-thirds of all woodlands are grazed (Huntsinger 1997). In addition to domestic livestock grazing, feral hogs consume

Table 19.4
Comparison of oak woodland conditions before European settlement, during extensive-ranching period, and in urban interface areas

Pre-European settlement	*Extensive-ranching period*	*Current urban*
Perennial herbaceous layer	Invasion of exotic annuals	Increasing annuals invasion, especially noxious weeds
Regular fire interval	Continuation of regular fire interval	Fire suppression policies, long fire interval, increased fire intensity
More-open overstory layer	Range clearing and tree thinning	Increased overstory layer of unconverted stands
Soil moisture higher and later into growing season	Soil moisture late in growing season decreased due to exotic annuals	Decreased soil moisture late in growing season due to exotic annuals
Lower soil density	Increased soil density	Increased soil density
Snags, large woody debris	Snags and woody debris cleaned up in typical management activities	Less attention to clean-up; increased snags and woody debris
Dense, diverse riparian zone	Riparian zones less dense and diverse	Higher human use of riparian zones, increased storm runoff from urban areas
Lower herbivore densities	Higher herbivore density, primarily domestic livestock	Decrease in domestic livestock

acorns, while rodents such as ground squirrels and pocket gophers utilize large quantities of acorns and seedlings.

Grazing has both positive and negative effects on oak woodland sustainability. Positive grazing effects include: reduced moisture competition between oaks and herbaceous material (Hall et al. 1992); reduced leaf area in seedlings, which may help conserve moisture late in the growing season (Welker and Menke 1990); habitat for rodents who consume acorns and young seedlings may be reduced; and fuel ladders are eliminated, reducing the probability of crown fires in grazed woodlands. Negative effects of livestock grazing include: livestock and other grazing animals consume oak seedlings and acorns (Swiecki et al. 1997, Adams et al. 1992, Hall et al. 1992); grazing may increase soil compaction, making root growth for developing oak seedlings more difficult (Gordon et al. 1989); and soil organic matter may be reduced.

The oak canopy has an effect on forage production, composition, and quality that varies around the state depending on precipitation, oak species, and amount of oak canopy cover. Oaks compete with the forage understory for both sunlight and moisture, and they alter the nutrient status of the site because of the deep rooting of oaks and nutrient cycling from litter fall.

Oak removal was historically recommended as a means of increasing forage production on hardwood rangelands (George 1987). For the deciduous blue oak, most studies have demonstrated increased forage production following tree removal on areas previously containing over 25% canopy cover and receiving over 20 inches of rain (Kay 1987, Jansen 1987). Conversely, where there is less than 20 inches of rain, areas with low blue oak canopy (less than 25% cover) consistently had higher forage yields than adjacent open areas (Holland and Morton 1980, Frost and McDougald 1989). In areas with moderate blue oak canopy cover (25% to 60%), there was a variable canopy effect on forage production (McClaren and Bartolome 1989a). In areas with less than 20 inches of rainfall, zones under the canopy had consistently higher forage production throughout the growing season. In areas with over 20 inches of annual rainfall, the open areas had higher forage production than the areas under the moderate oak canopy.

Blue oak, in the southern and central portion of its range, provides green forage earlier (in the presence of adequate rainfall) and in higher quantities (15% to 100% greater) compared to the forage in open areas (Holland 1980, Frost and McDougald 1989, Ratliff et al. 1991); the difference in forage quality and quantity (though not necessarily timing of initial growth) may be even more pronounced during drought, due to the shading provided by tree canopies and the consequent reduction in moisture loss through evapotranspiration (Frost and McDougald 1989).

In evergreen live oak stands, with leaves that shade forage growth during the winter and early spring months, the few studies that have been carried out show a larger competitive effect of oaks on forage production (Ratliff et al. 1991). In general, live oaks stands with over 25% canopy cover will have lower forage growth than cleared areas. However, one study in the southern foothills of the Sierra Nevada showed that in drought years, live oak shading helped conserve soil moisture, resulting in higher forage production than on open sites (Frost and McDougald 1989). Table 19.5 summarizes the results of research studies of the relationship between oak canopy and forage production (Frost et al. 1997).

The increase in forage production beneath blue oak canopies, or in

Table 19.5
The effect of density of oak canopy on hardwood rangeland forage production

Species group	*Canopy cover*	*Winter forage production*	*Spring forage production*
Live oaks	Scattered (< 10% cover)	Varies	Varies
	Sparse (10–25% cover)	Varies	Varies
	Moderate (25–60% cover)	Inhibited	Inhibited
	Dense (> 60% cover)	Inhibited	Inhibited
Deciduous oaks	Scattered (< 10% cover)	Enhanced	Enhanced
	Sparse (10–25% cover)	Enhanced	Enhanced
	Moderate (25–60% cover)	Varies	Varies
	Dense (> 60% cover)	Inhibited	Inhibited

Source: Adapted from Frost et al. 1997.

areas previously beneath blue oak canopies, is attributed, in part, to increased soil fertility caused by leaf fall and decomposition (Jackson et al. 1990, Frost and Edinger 1991, Firestone 1995). Enhanced soil fertility also improved forage quality beneath blue oaks or where blue oaks had been removed. However, since the nutrient input from leaf litter ceases after tree removal, forage production increases will be temporary, gradually declining until soil fertility reaches levels similar to those in adjacent open areas. Long-term studies have found that it may take 15 years for this nutrient effect from oak cover to dissipate after tree removal (Kay 1987).

Oak canopies also have an effect on forage species composition. Studies have found that understories of both blue and live oak stands favor later successional herbaceous species, such as wild oats (*Avena fatua*), soft chess (*Bromus mollis*), and ripgut brome (*Bromus diandrus*). Clovers (*Trifolium* spp.), annual fescues (*Vulpia* spp.), filaree (*Erodium* spp.), and soft chess account for more of the total herbage biomass in open areas than under oak canopy (Ratliff et al. 1991, Holland 1980).

In general, managers of livestock enterprises on hardwood rangelands should consider the following general guidelines when managing their oaks (Standiford and Tinnin 1996):

There is little or no value in removing blue oaks in areas with less than 20 inches of annual precipitation.

On areas with over 20 inches of annual rainfall, thinning oaks where the canopy exceeds 50% will have the greatest effect on forage production.

In areas thinned for forage enhancement, residual tree canopies of 25% to 35% are able to maintain soil fertility and wildlife habitat and to minimize erosion processes.

Tree removal activities should always be planned, considering all values of the trees, including wildlife habitat, soil stability, etc. in addition to the possible forage production benefits.

Soil Processes and Nutrient Cycling

In an investigation of soil-associated characteristics under canopies of different tree species and in open grassland sites, Frost and Edinger (1991) found higher organic carbon levels, greater cation exchange capacity, lower soil density, and greater concentrations of some nutrients (at a soil depth of 0–5 cm) under blue oak canopies than in open grassland. Organic matter input from blue oak leaf litter primarily accounts for this finding; leaching of nutrients from rainwater drip may also make a significant contribution. The soil conditions beneath interior live oak and blue oak are similar; shading from the evergreen canopy, therefore, is thought to primarily account for the reduced total annual herbage production below interior live oaks under moderate environmental conditions (Frost and Edinger 1991). This may at least partially account for the higher production under blue oak canopies as compared to open grassland sites in the central Sierra Nevada foothills. Upon removal of overstory blue oak species, there is a gradual decline to levels comparable to the open grassland (Holland 1980, Kay 1987). Frost and Edinger (1991) attribute this to the reservoir of nutrients in blue oak litter, which is gradually depleted over time.

Oak woodlands with perennial grasses keep soil moisture later into the growing season than do woodlands with annual grasses (Gordon et al. 1989). This difference in soil moisture may partially explain the observed lack of sapling recruitment in oak woodlands. Evaluation of hardwood rangeland soil density shows that areas with livestock grazing have a higher density than ungrazed areas.

Working in the foothills of the Sierra Nevada, Jackson et al. (1990) found that soils under blue oak canopies have higher nitrogen turnover rates and inorganic nitrogen contents than surrounding open grassland soils, due primarily to the higher nitrogen content from mineralization of oak leaf litter. There was no difference in soil water potential between the understory and the open grassland. The increased fertility under the blue oak canopy did not result in enhanced forage productivity; however, blue oaks do maintain a reservoir of soil organic nitrogen that could be rapidly depleted if the oaks were removed.

Oak Regeneration and Recruitment Processes

One of the key concerns that landowners, policy makers, and the public have about the state's hardwood rangelands is whether there is adequate oak regeneration to sustain current woodlands and savannas. Several surveys of oak regeneration (Bolsinger 1988, Muick and Bartolome 1987, Standiford et al. 1991, Swiecki et al. 1997) have shown a shortage of trees in the sapling size class for certain species (especially blue oak, Engelmann oak, and valley oak) in certain regions of the state (sites at low elevation, on south- and west-facing slopes, on shallow soils, or with high populations of natural or domesticated herbivores). If this shortage of small trees continues over time, then the oak stands may gradually be lost as natural mortality factors or tree removal take their toll on the large, dominant trees in the stand and woodlands convert to other vegetation types such as brushfields or grasslands.

Local deciduous oak regeneration was abundant prior to 1900. Present stand structure suggests that oak regeneration was more frequent in the past. However, deciduous oaks have reproduced poorly in the past 50 years (Griffin 1977). While seedlings do become established, few develop into saplings. Live oaks, whose seedlings may be more resistant to grazing and browsing than are those of the deciduous oaks, have produced saplings with more success over the past few decades. Pocket gophers, a significant seedling predator, may prefer deciduous oak roots to those of live oaks. Much of the failure of deciduous oak seedling establishment may be attributed to acorn and seedling damage by cattle, deer, rodents and insects (Griffin 1977).

According to demographic studies and experimental research, older individuals dominate most extant blue oak populations; current recruitment levels are insufficient to maintain the present distribution of blue oak (Davis 1995, Swiecki et al. 1997). Valley and blue oak are not regenerating in sufficient numbers to maintain existing stands (Muick and Bartolome 1987). However, the causes and mechanisms, which seem to vary according to species, region, and site, are still under investigation (Bartolome 1987).

Current research indicates that present recruitment of blue oaks may arise from a gap mechanism by which an understory seedling bank persists until a moderate stand disturbance (such as clearing, fire, or natural tree mortality) occurs, after which sapling recruitment proceeds (Swiecki et al. 1997). Natural blue oak regeneration is thus a multiple-step process that requires many years for completion. When grazing pressures and plant competition are minimal (such as along roadsides beyond pastures) or where microhabitat is favorable, pioneer establishment of blue oaks in open sites can occur. However, the seedling bank–gap–sapling recruitment mechanism, or seedling advance regeneration, seems to be the most pervasive mode of natural blue oak recruitment and regeneration. Undisturbed sites with moderate to dense oak canopies are unlikely sites for sapling recruitment. Since there are various steps and life history stages involved in the seedling advance regeneration mechanism, several variables affect regeneration at different stages of the recruitment process.

Swiecki et al. (1997) evaluated the status of stand-level blue oak regeneration and examined how management tools, environmental factors and site history affect blue oak sapling recruitment at 15 different blue oak–dominated locations. Saplings (basal diameter of 1 cm or greater and a diameter at breast height [dbh] of 3 cm or less) were found on 15.3% of the plots; the majority of these had grown from seedlings as opposed to sprouting from cut stumps. Based on observed mortality and sapling recruitment, 13 out of 15 sites had a net loss in blue oak density and canopy cover. These results differ from the earlier discussions on stand-level stability and demonstrate the need for long-term regeneration monitoring. Statistical analysis showed variables such as topographic position, browsing intensity, recent canopy gaps and clearings, and total overstory and shrub cover were associated with sapling recruitment at most of the study locations. Insolation, soil water holding capacity, and repeated fire were important at some locations.

Swiecki et al. (1997) propose the following recommendations to enhance blue oak recruitment:

Minimize understory shrub clearing in blue oak communities.
Reduce the intensity and duration of browsing pressure on woody vegetation.
Employ fire to manipulate understory vegetation so as to favor recruitment.
Leave intact at least 20% overstory canopy cover within 0.1 ha unit of regeneration sites.
Following gap creation, minimize livestock use until blue oak saplings are taller than browse level.
Minimize "potentially adverse impacts" in sites near the limits of blue oak range.

Valley oak has experienced inadequate regeneration during the past century (Griffin 1973, Bernhardt and Swiecki 1991, and Danielsen and Halverson 1991). Seedlings do become established, but few develop into saplings. Invasion of alien annual grasses, which make less water available to oaks than do native perennial grasses, may be one cause of this effect.

Stump sprouting has been widely observed in most oak woodland species. Studies have shown a high probability of achieving stump sprouting for blue and live oak species. This observation reduces the concern expressed over a lack of sapling trees in these woodlands (McCreary et al. 1991, Standiford et al. 1996).

Figure 19.1 is a chart that may help hardwood range landowners and managers assess oak regeneration (Standiford and Tinnin 1996). It shows that there are several questions to be raised in considering the process of oak regeneration (Bartolome et al. 1987). First, there needs to be an assessment of the current stand structure and whether it is consistent with the objective for the stand. Second, the health and vigor of the existing trees need to be assessed to determine if recruitment of small trees is needed to offset future tree mortality. Third, the number of seedling and sapling trees should be evaluated. In areas where trees have died, seedlings and saplings will be needed to replace the lost trees. When overstory density is below the desired level for management objectives, seedlings and sapling trees will be needed to increase tree density.

Oak Restoration and Planting

On areas that have been determined to have a regeneration problem, it may be necessary to establish more oaks. Planting acorns or seedlings

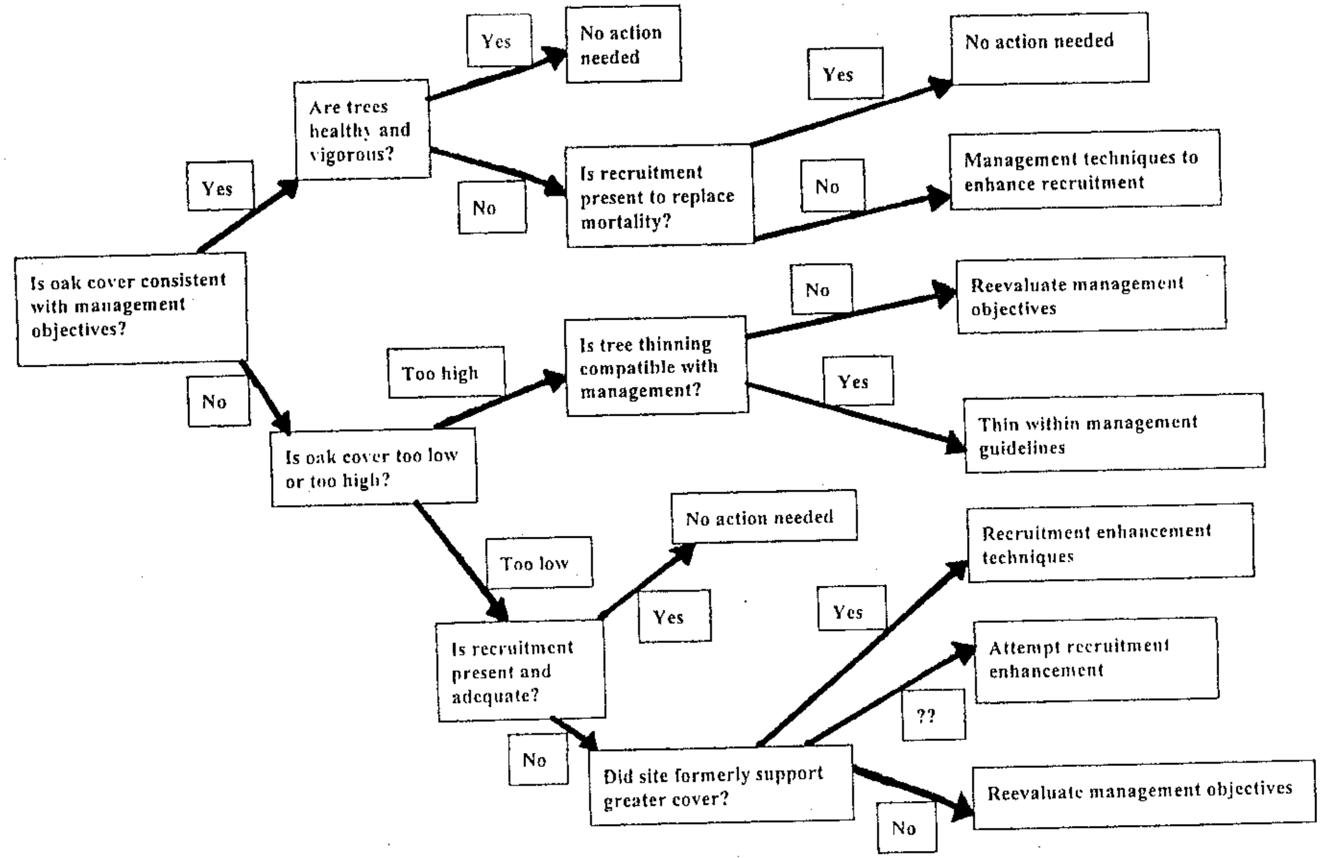

FIGURE 19.1. Decision key to aid evaluation of oak regeneration on hardwood rangeland.

may be necessary where recruitment is inadequate to maintain oak cover on a long-term basis. However, the same factors that limit natural oak regeneration can inhibit artificial regeneration of native oaks. In general, substantial care must be taken to plant, protect, and maintain young oaks in the field to ensure success.

Riparian Management Processes

Although a small percentage of the state's water supply originates in hardwood rangelands, virtually all of it flows through oak woodland riparian zones (California Department of Forestry and Fire Protection 1988). Also, most of the state's major reservoirs are located on oak woodlands. Riparian zones provide important habitat for wildlife and aquatic organisms. Management activities influence water quality and wildlife and fisheries habitat. Yet, removal of up to one-third of the oak canopy had little effect on water quality and yield in one regional study (Epifanio et al. 1991). As part of the state's water quality management plan, new rangeland management practices are being developed (Humiston 1995). In urban interface areas, riparian zones are often subject to very high levels of human use for recreational purposes. Scott and Pratini (1997) documented how urban development increases human use of riparian areas, lowering the habitat value for various wildlife species and decreasing overall biological diversity.

Fire Ecology Processes

Fire is an important ecosystem process and management tool in oak woodlands. It affects oak woodland stand structure, oak regeneration processes, wildlife habitat, nutrient cycling, and economic uses for domestic livestock. The ecological effects of fire depend on its frequency, timing, and intensity, as well as the patch size from fire-induced mortality. The burning intensity and timing of adjacent vegetation types, such as chaparral and montane forests, influence fire effects in oak woodlands. Recent increases in the acreage damaged by stand-destroying fires in oak woodlands—the result of decades of attempting to exclude fire from wildland areas—point to the need to develop strategies that include fire in management activities if we are to sustain the economic and ecological values of our oak woodlands.

Fire Frequency. Because of the long period of human habitation of oak woodlands, it is extremely difficult to separate the "natural" role of fire from the human use of fire as a management tool. Lightning fires have helped shape oak woodlands. Lightning-caused fires originate from major storms coming northward from Mexico. It is speculated that decades may pass between major lightning-caused fire events in oak woodlands (Griffin 1977). Oak woodlands are extremely well adapted to hot summer fires (Mooney 1977). Mature oaks can survive regular low-intensity ground fires, and the young seedlings and saplings of most woodland oak species have the capacity to resprout after being top-killed by fire.

Native Americans made frequent use of fire in their stewardship of oak woodlands (Holmes 1990). There are numerous accounts of Native Americans using burning in woodlands to enhance habitat for game species, to improve access for hunting and gathering of acorns, and to maintain plant materials in an appropriate growth form for crafts (Jepson 1910, Cooper 1922). However, it is almost impossible to document the frequency, intensity, and extent of burning by Native Americans from existing fire ecology studies.

The first European settlers in oak woodlands continued to use fire as a management practice, to keep stands open for livestock production and to encourage forage production. Records indicated oak woodland burning intervals of 8 to 15 years by ranchers (Sampson 1944). Local prescribed burning associations were set up in various locations around the state, where neighbors came together annually to help conduct burns in the highest priority areas.

The use of burning as a management tool to mimic the effects of nature ceased on the state's conifer forest lands in the early part of the century. However, ranchers continued the extensive use of planned burning until the 1950s. At that time, the use of fire in oak woodlands declined, curtailed by negative urban attitudes towards fire, increasing housing density in rural areas of the state, concerns about liability from escaped prescribed fires, and air quality concerns. Fire suppression became the standard management strategy on oak woodlands, as it had become decades earlier on conifer lands.

McClaren and Bartolome (1989b) evaluated fire frequency in Central Sierra oak woodlands. Fire frequency had been around 25 years prior to settlement by Europeans in the mid-1800s. After settlement by Europeans, fire frequency became about every 7 years. No fires were observed from 1950 until the mid-1980s, when fire suppression was the dominant practice. Stephens (1997) observed similar fire frequencies in the central Sierra Nevada.

Effects of Fire on Oak Woodland Sustainability. Higher fire frequencies in the past may have created conditions more conducive to oak regeneration. McClaren and Bartolome (1989b) compared the age structure of oak stands with fire history and showed that oak recruitment was associated with fire events. Most oak recruitment in their Central Sierra study area occurred during periods of high fire frequency during the 1880s to 1940s. Oak recruitment has been rare since fire suppression.

The reasons that higher fire frequency enhances oak regeneration are not entirely clear. Allen-Diaz and Bartolome (1992) looked at blue oak seedling establishment and mortality and the practices of grazing and prescribed burning in coastal areas of hardwood rangelands. Neither grazing nor burning significantly affected oak seedling density nor the probability of mortality when compared to ungrazed and unburned areas, suggesting that seedling establishment is compatible with grazing and fire. Lawson (1993) studied the effect of prescribed fire on coast live oak and Engelmann oak in southern California and found higher seedling mortality in areas of prescribed fire.

Perhaps the importance of fire to oak regeneration is explained by its enhancement of oak sprout growth, which has been documented by Bartolome and McClaren (1989b). They concluded that in areas of moderate grazing with fire intervals of around 7 years, seedlings taking up to 18 to 20 years to exceed the livestock browse line (around 5 feet) would survive to become saplings and persist in the stand. In heavily grazed areas, only those trees that exceeded the browse line in 10 to 13 years would be recruited. Other factors affecting oak regeneration which would be influenced by the timing of fire events include the seedbed for acorns, the competition for moisture from herbaceous species, and the habitat for wildlife species that feed on acorns and seedlings.

Fire also has a major effect on the structure and composition of oak woodland stands. Lawson (1993) showed the differential effects of fire on coast live oak and Engelmann oak stands. Coast live oak had a higher mortality than Engelmann oak following fire. Coast live oak had greater height growth in unburned areas, while Engelmann oak had greater height growth following fire. The thicker bark of Engelmann oak provided more protection for the Engelmann oak sprouts. The study concluded that concerns about the decline of Engelmann oak habitats in southern California might be mitigated by reintroduction of fire to encourage Engelmann oak in these mixed stands.

Fire also kills diseases and pests, such as the filbert weevil (*Cucurlio occidentalis*) and the filbert worm (*Melissopus latiferreanus*), both of which can infest the acorn crop (Lewis 1991); and it reduces fuel ladders under oak canopies, preventing high-intensity crown fires.

Wildlife Habitat and Biodiversity Processes

California's hardwood rangelands provide habitat for over 300 vertebrate wildlife species, more than 2,000 plant species, and an estimated 5,000 species of insects. Figure 19.2 illustrates the diversity of vertebrate wildlife species predicted by the California Wildlife Habitat Relationships model for each of the five major hardwood rangeland habitat types (Mayer and Laudenslayer 1988). The management and long-term sustainability of California's hardwood rangeland habitats will best be served if ecological components and their interrelationships are recognized and addressed by owners and managers.

Wildlife are abundant inhabitants of the oak woodlands; the persistence of this varied wildlife can only be assured by maintaining the diverse habitats contained within the Sierra Nevada oak woodlands. These wildlife species depend on the oak trees, shrubs, grasses, forbs, seeds,

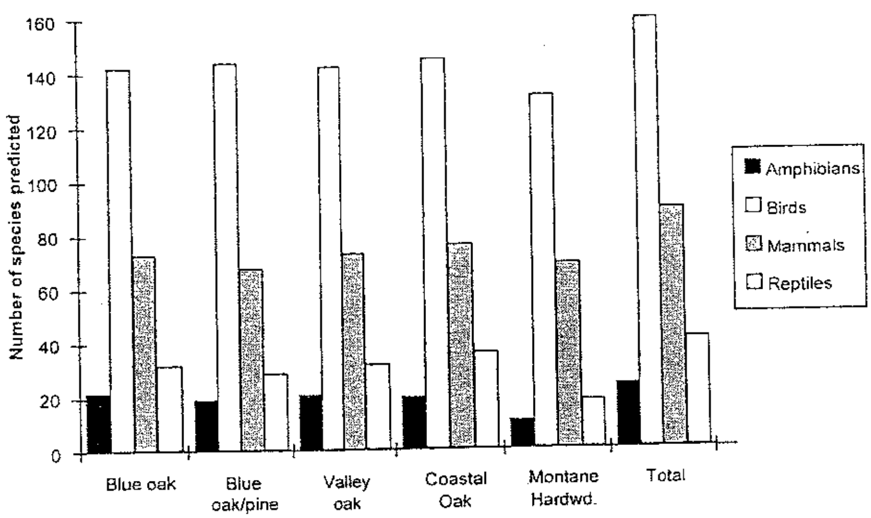

FIGURE 19.2. Numbers of amphibians, birds, mammals, and reptiles estimated to occur in the five California hardwood rangeland habitats described in the California Wildlife Habitat Relationships System. This list includes only those species in the system that are estimated to use one or more tree size and canopy cover classes for breeding, feeding, and/or cover.

fruits, insects, and other components of the oak woodland system. Much of the wildlife diversity is directly related to the diversity of trees, shrubs, logs, leaf litter, grasses, forbs, and other habitat components (Block 1990). A change in one of these components (such as alteration in tree density through urbanization or fuelwood removal) changes other factors (light regime, shrub layer, leaf litter, etc.).

In a three-year study of nongame wildlife populations at the Sierra Foothill Research and Extension Center, Block and Morrison (1990) found 113 bird species (at least 60 of which bred at the site), including 43 year-round residents, 11 winter residents that bred elsewhere, 17 breeding species that wintered elsewhere, 21 migrant birds, and 21 incidental species (Block 1990). Much of the bird species diversity is directly related to the plant diversity in oak woodlands. For example, Hutton's vireo (*Vireo huttoni*), orange-crowned warbler (*Vermivora celata*), and Wilson's warbler (*Wilsonia pusilla*) are closely associated with interior live oak. Birds such as the white-breasted nuthatch (*Sitta carolinensis*) and western bluebird (*Sialia mexicana*) are closely associated with blue oak (Block 1990). Wintering and migrant birds rely on the woodland resource for survival. Moreover, the specific habitats utilized by the birds change seasonally. For example, many resident birds obtained insects from foliage of blue and interior live oaks during the breeding season but were restricted to live oaks when the blue oaks had shed their leaves.

Block and Morrison (1990) recorded five small mammal species, including the brush mouse (*Peromyscus boylii*), pinyon mouse (*P. truei*), deer mouse (*P. maniculatus*), dusky-footed woodrats (*Neotoma fuscipes*), and ornate shrews (*Sorex ornatus*). They found low numbers of small mammals in their study sites and hypothesized that the indictment of small mammals as a major inhibitor of white oak regeneration is premature.

Block and Morrison (1990) found one amphibian species (the California slender salamander [*Batrachoseps attenuatus*]) and three reptile species (the western fence lizard [*Sceloporus occidentalis*], western skink [*Eumeces skiltonianus*], and the southern alligator lizard [*Gerrhonotus multicarinatus*]) in their Sierra Nevada sites. Distribution of the California slender salamander was limited to interior live oak stands, while western fence lizard and the southern alligator lizard and western skink were found in both live and blue oak stands.

Favorable hardwood rangeland habitats supply food, water, and cover to sustain wildlife species. Each habitat element provides unique niches, favoring particular wildlife species. Conversely, the absence of a particular element in a habitat may limit species diversity. Examples of elements of a hardwood rangeland habitat that are important to consider include riparian zones, vernal pools, wetlands, dead and downed logs and other woody debris, brush piles, snags, rock outcroppings, and cliffs.

Riparian habitat elements are used by almost 90% of all hardwood rangeland wildlife species, illustrating the importance of conserving this habitat element where present. Over one-third of all bird species on hardwood rangelands make use of snags, suggesting that management strategies maintaining an appropriate number of snags will result in greater wildlife species diversity. Downed woody debris from fallen limbs or dead trees provide an extremely valuable habitat for most reptiles and amphibians, as well as for many bird species. Oak woodland management for wildlife must retain dead trees along with trees in various stages of vigor in order to maintain critical wildlife habitat (Block et al. 1990). Mid-elevation hardwood rangeland habitats with several oak species, vertical diversity in vegetation structure, and diverse riparian zones have the richest diversity of wildlife (Motroni et al. 1991).

The threats to continued high biodiversity on hardwood rangelands include (1) fragmentation of large blocks of extensively managed hardwood rangelands; (2) reduction in important habitat elements such as snags, woody debris, and diverse riparian zones; and (3) increasing interface with urban areas, bringing household pets, humans, and fire suppression policies into contact with hardwood rangeland habitats. These threats to biodiversity can be reduced by encouraging cluster development and conservation of connecting corridors between large hardwood rangeland habitat blocks (Giusti and Tinnin 1993).

Conclusion

Oak woodlands are an important ecological component in California. Sustainability of ecological values is threatened by rapid population growth and the resulting conversion and fragmentation of woodland habitats. Many counties have started adopting local conservation strategies to conserve oak woodlands. Education and research have played a major role in conservation. Significant accomplishments have been made in rural areas of the state, where livestock and natural resource management are the predominant land uses. Where individual landowners have the ability to implement management activities that affect large acreage, education and research have contributed to decisions that favor conservation of oak woodlands.

However, for much of California, conversion of oak woodland habitats to urban or suburban land use is having a dramatic impact on sustainability of resource values. Incorporation of ecological information into land use plans adopted by county governments is only beginning. Since conversion to residential and industrial uses is ultimately a land use decision, it is a political process involving action by elected officials and input from different constituencies. The political and economic forces vary greatly in different parts of the state. Since success in this area will require that multiple individuals agree on a political course of action, this issue will present a large challenge.