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Sustainability of Sierra Nevada Hardwood Rangelands

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ABSTRACT

Close to 800,000 acres of hardwood rangelands (also known as oak woodlands) in the Sierra Nevada have been converted to other land uses and vegetation types over the last 40 years, a decline of almost 16 percent. Major losses from 1945 through 1973 were from rangeland clearing for enhancement of forage production. Major losses since 1973 were from conversions to residential and industrial developments. Exurban migration represents the largest threat to continued sustainabiltiy of ecological functions on hardwood rangelands. This has increased fragmentation of habitat, conflicts between people with rural and urban value systems, predator problems, and soil and water erosion. At the individual stand or patch level, oak woodlands are much more stable than previously thought due to concerns about oak regeneration. Long-term trends reveal stand structures with recruitment into various size classes and increasing canopy density under typical livestock management practices. Technologies have been developed to carry out restoration of areas denuded of oaks in the past. Voluntary educational programs have made dramatic progress in accomplishing sustainable management practices by ranchers. It is less certain if the currently unregulated land use trends can be influenced by voluntary programs.

Keywords: hardwoods, rangelands, oaks

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California's oak woodlands, also known as hardwood rangelands, occupy over 10 million acres in the state (Bolsinger 1988; Greenwood et al.1993; Pacific Meridian Resources 1994). These oak woodland areas are characterized by an overstory canopy of hardwood tree species, predominantly in the oak genus (*Quercus spp.*), with an understory of annual grasses and occasional native perennial grasses. Approximately 30 percent of this acreage in in areas with less than 10 percent tree canopy cover. Griffin (1978), Bartolome (1987) Holmes (1990) and Allen et al.(1991) provide good ecological descriptions of these areas.

Since European settlement of California, oak woodlands have been managed primarily for livestock production. These areas have taken on a new importance because of the recognition that they have the richest wildlife species abundance of any habitat in the state, with over 300 vertebrate species relying at least partly on oak woodlands (Verner 1980; Barrett 1980; Garrison 1996). Other public values obtained from these areas include water quantity and quality, outdoor recreation, and aesthetics. California's oak woodlands are somewhat unique for western wildlands, with over 80 percent in private ownership (Greenwood et al. 1993).

There are 4.7 million acres of hardwood rangeland in the Sierra Nevada region. Table 1 shows the acreage by county and hardwood rangeland plant community (see next section for discussion of plant communities). Private ownership occurs on 85 percent of Sierra Nevada hardwood rangelands. These areas are concentrated in the western foothills of the Sierra Nevada extending from the xeric lower grasslands and savannahs of the central valley up to the more mesic higher elevation mixed hardwood and coniferous forests. The foothills form a belt from 20 to 30 miles wide and from 450 to 4500 feet in elevation along the eastern border of the central valley.

Conservation strategies for hardwood rangelands in the Sierra Nevada need to recognize the widespread extent of this broad habitat type, its importance for the economic livelihood of the region, and their important ecological values. This paper will assess the sustainability of hardwood rangelands in the Sierra Nevada. The definition of sustainable includes the following considerations:

- maintain ecosystem processes at multiple scales;
- maintain the existing diversity of biological organisms;
- maintain economic viability over the long-term.

Each of these items will be discussed in some detail below.

Table 1. Acreage of Sierra Nevada hardwood rangeland by county, vegetation type, and private ownership.

County	Thousand Acres				Pct. Private Ownership
	Blue oak[1]	Blue oak - foothill pine	Montane Hardwood	Total Hardwood Rangeland	
Shasta	71	212	4	287	97%
Tehama	285	332	17	634	83%
Butte	5	82	143	230	91%
Yuba	2	12	81	95	86%
Nevada	0	9	130	139	91%
Placer	5	0	100	105	90%
Eldorado	4	25	149	178	94%
Amador	38	79	61	178	97%
Calaveras	74	102	141	317	91%
Tuolumne	60	87	87	234	75%
Mariposa	130	80	89	299	88%
Madera	137	89	58	284	93%
Fresno	222	222	49	493	74%
Tulare	357	110	69	536	73%
Kern	657	26	38	721	78%
Sierra Totals	2047	1467	1216	4730	84%

[1] Includes trace amounts of valley oak woodland

CLASSIFICATION OF OAK WOODLANDS

A variety of systems have been used to classify oak woodlands in California. Table 2 provides a general cross-reference of these various classification systems. The distribution, density, and abundance of the various oak species, together with other tree, brush, and herbaceous species, forms the basis for evaluating the potential of a hardwood rangeland site for providing economic and ecologic utility. Although there are a number of different ways of classifying California's oak-dominated woodlands, the four vegetation types used in the California Wildlife Habitat Relationships System (CWHR) will be used in this discussion (Mayer and Laudenslayer 1988). The CWHR types for the Sierra Nevada hardwood rangelands are based on the dominant tree species, and include Valley Oak Woodland, Blue Oak Woodland, Blue Oak-Foothill Pine Woodland, and Montane Hardwood Forest. A brief description of each type is shown below. This material is excerpted from Garrison and Standiford (1996).

Table 2. Cross-reference for hardwood rangeland classification in the Sierra Nevada.

Allen et al. 1991	CALVEG	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 Phase North Slope Phase	Foothill Woodland	***	***	Montane Hardwood
***	Canyon Live Oak	Blue Oak and Interior Live Oak Phases	Foothill Woodland	Sierran Montane Forest	Canyon Live Oak	Montane Hardwood Conifer and Montane Hardwood
Black Oak Series	Black Oak	Black Oak Phase	Foothill Woodland	Sierran Montane Forest	California Black Oak	Montane Hardwood Conifer and 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

<u>Valley Oak Woodland</u> (from Garrison and Standiford 1996)

<u>Vegetation Composition and Structure</u>

These woodlands are dominated by valley oaks (*Quercus lobata*). Associated tree species in the Central Valley include California sycamore (*Platanus racemosa*), black walnut (*Juglans hindsii*), California boxelder (*Acer negundo*), Oregon ash (*Fraxinus latifolia*), interior live oak (*Q. wislizenii*), and blue oak (*Q. douglasii*). California black oak (*Q. kelloggii*) often occurs with valley oaks at higher elevations. At low elevations close to water, valley oak is associated with Fremont cottonwood (*Populus fremontii*) and tree willows (*Salix* spp.). Valley oak woodlands vary from open savannahs to closed canopy forests. Dense stands occur along natural drainages in deep soils. Tree density decreases as one moves from lowlands to uplands. The understory shrub layer can be dense along drainages and very sparse in uplands. Understory grasses and forbs are mostly introduced annuals. Mature valley oaks with well-developed crowns reach - maximum heights of 50-120 ft. The massive trunks and branches of mature trees dominate valley oak woodlands.

<u>Ecological Processes</u>

In many areas, there is little valley oak recruitment to replace mature tree losses due to both natural and human causes. This seems to be related to moisture competition with grasses and forbs, wild and domestic animals feeding on acorns and seedlings, and flood control projects. Fire suppression has encouraged evergreen oak and pine invasion in upland valley oak sites. Valley oaks tolerate flooding and young trees will sprout when damaged by fire. Valley oak woodlands should be able to maintain themselves with natural disturbances such as fire and flooding. However, suppression of fire and flooding has adversely affected sustainability of valley oak woodlands.

Locational Characteristics

Valley oaks are found only in California. In the Sierra Nevada region, they occur in a patchy distribution adjacent to most major lowland valleys. Many valley oak woodlands occur as isolated stands in areas where surrounding habitats have been modified by agricultural, urban, and suburban activities. Annual grasslands, riparian forests, and other oak woodland types occur around valley oak woodlands. Conversion of valley oak woodlands to irrigated agricultural land uses has had the largest effect on the acreage decline of this type, currently estimated at less than 10 percent of its initial distribution. Valley oak communities generally occur on deep, well-drained alluvial soils of valleys and foothills below 2,400 feet, but may occur up to 5,600 feet as components of other vegetation types.

Blue Oak Woodland (from Garrison and Standiford 1996)

Vegetation Composition and Structure

Blue oak woodlands are highly variable with blue oak (*Q. douglasii*) comprising 80-100 percent of the trees present. Foothill pine (*Pinus sabiniana*), California buckeye (*Aesculus californica*), valley oak, interior live oak, canyon live oak (*Q. chrysolepis*), and California black oak are common associates of blue oak. The overstory of blue oak woodlands range from sparsely scattered trees on poor sites to nearly closed canopies on good quality sites . Annual grasses form most of the understory in open woodlands. Characteristic shrub species include poison-oak (*Toxicodendron diversilobum*), California coffeeberry (*Rhamnus californica*), and several species of Ceanothus and manzanita.

Ecological Processes

Blue oaks are relatively slow-growing, long-lived trees. Most blue oak stands exist as groups of medium to large trees with few or no young oaks, which may or may not indicate there is a regeneration problem. There is concern that in areas of poor regeneration, blue oak woodlands may be slowly changing into savannas and grasslands as trees die and are not replaced. Fires are an important environmental factor. Young, vigorous blue oaks can stump sprout readily, however, older, decadent trees cannot. Therefore, younger stands are more likely to regrow after fires. Poor blue oak recruitment from acorns occurs for several reasons. Introduced annual grasses out-compete blue oak seedlings for soil moisture. In addition, acorns and seedlings are eaten or damaged by insects, domestic livestock, and wildlife. Blue oak is also somewhat intolerant of shady conditions, and is unable to survive under dense overstory canopies. Disturbances with small openings may be needed for seedlings to survive and grow sufficiently to promote a broader age class distribution.

Locational Characteristics

Blue oak woodlands form a nearly continuous band along the Sierra Nevada-Cascade foothills of the Sacramento-San Joaquin Valley. Typically, blue oak woodlands are found below 3,000 to

4,000 feet, but this elevational threshold drops to around 2,000 feet in the northern range, and raises to around 5,000 feet in the southern range. At lower elevations on gentle slopes, blue oak woodlands typically occur as large blocks with highly variable canopy cover. On steeper ground, blue oak woodlands occur in small patches interspersed with other habitats such as annual grasslands, chaparral, riparian forests, and other types of oak woodlands. Blue oak woodlands occur on a wide range of soils, however, they are often shallow, rocky, infertile, but well-drained. There is considerable climatic variation with rainfall ranging from 10 to 60 inches annually.

Blue Oak-Foothill Pine Woodland (from Garrison and Standiford 1996)

Vegetation Composition and Structure

Foothill pine (formerly known as digger pine) and blue oak typically form most of the overstory of this highly variable community, with blue oak usually most abundant. Stands dominated by foothill pine have low blue oak density because of its shade intolerance. In the Sierra Nevada foothills, interior live oak and California buckeye are often associated with this type. Interior live oak becomes more abundant on steeper slopes, shallower soils, and at higher elevations. Shrub associates include several ceanothus and manzanita species, poison-oak and California redbud (*Cercis occidentalis*), and are usually clumped in areas of full sunlight. Blue oak-foothill pine woodlands have a diverse mix of hardwoods, conifers, and shrubs, and widely variable overstories. Foothill pine is taller and dominates the overstory.

Ecological Processes

Blue oak and foothill pine are relatively long-lived, but foothill pine tends to grow faster than blue oak. Fairly frequent fires historically occurred in this vegetation community. Regeneration is generally thought to be infrequent throughout California. Young, vigorous blue oaks sprout well, but older, more decadent trees do not. Therefore, younger stands are more likely to replace themselves after fires.

Locational Characteristics

Blue oak-foothill pine woodlands are found on steeper, dryer slopes with shallower soils than blue oak woodlands. At lower elevations on gentle slopes, these two communities intermix with grasslands. At higher elevations on steeper slopes, the communities are mixed with grasslands and shrublands. Riparian woodlands may bisect these mosaics along permanent and intermittent watercourses. Blue oak-foothill pine woodlands are found throughout the range of blue oak and form a nearly continuous band along the Sierra Nevada-Cascade foothills of the Sacramento-San Joaquin Valley, except for a gap in Tulare and southern Fresno counties. Elevation ranges from 500 feet in the north to 3000 feet in the south.This woodland type occurs on a variety of well-drained soils. Terrain is hilly and generally dry, and water is unavailable for much of the year.

Montane Hardwood Forest (from Garrison and Standiford 1996)

Vegetation Composition and Structure

Montane hardwood forests are perhaps the most variable of any California hardwood type. The dominant oak species vary by topography, soils, and elevation. Montane hardwood forests typically lack blue and valley oaks. The characteristic oaks are canyon live oak, interior live oak, California black oak, and Oregon white oak. Many areas of montane hardwood forest are located on fairly productive forest soils, and are not truly "hardwood rangelands" but commercial hardwood forests under the jurisdiction of the California Forest Practices Act.

Canyon live oak often forms almost pure stands on steep canyon slopes and rocky ridgetops throughout the Sierra Nevada and Klamath Mountains. They have tremendously variable growth forms, ranging from shrubby forms with multiple trunks on rocky, steep slopes, to 60 to 70 foot tall trees on deeper soils in moister areas. California black oak tends to dominate on gentle topography at higher elevations. It grows to heights of 70 to 80 feet at maturity, with long, straight trunks in closed canopy situations. In open forests, California black oak has larger, spreading branches. Canyon live oak and California black oak are widely distributed and form the montane hardwood habitats throughout much of the Sierra Nevada. However, these two species are usually not associated with hardwood rangeland sites.

Interior live oak occurs with canyon live oak or alone on steep canyon slopes and rocky, steep slopes throughout the Sierra Nevada. It growth form varies much like canyon live oak. Both of these evergreen oaks have dense canopies. Oregon white oak dominates small amounts of montane hardwood types in the northern Sierra Nevada and Cascades. It grows to a height of 50 to 80 feet at maturity, with rounded crowns in open conditions and rather narrow crowns in closed conditions.

Associates of montane hardwood communities at higher elevation, good quality sites include ponderosa pine (*Pinus ponderosa*), Douglas-fir (*Pseudotsuga menziesii*), Pacific madrone (*Arbutus menziesii*), Jeffrey pine (*Pinus jeffreyii*), sugar pine (*Pinus lambertiana*), incense-cedar (*Calocedrus decurrens*), and white fir (*Abies concolor*). At lower elevations and poor sites with steep slopes, associates include foothill pine, knobcone pine, tanoak (*Lithocarpus densiflorus*), and Pacific madrone. Blue oak and valley oak can be associates at lower elevations. Understory shrub species include poison-oak, Ceanothus, manzanita, mountain-mahogany, coffeeberry, wild currant (*Ribes spp.*), and mountain misery. Forbs and grasses are not as prevalent as on lower elevation hardwood rangeland types. Montane hardwoods have a pronounced hardwood tree layer with poorly developed shrub and herbaceous layers.

Ecological Processes

Since oaks of montane hardwood communities are long-lived and slow-growing, the community is rather stable and persistent. Initial tree establishment is by acorn. Once established, the four dominant oaks, canyon live, interior live, California black, and Oregon white, can sprout vigorously from stumps, allowing rapid re-establishment after a fire. Frequent fires over relatively small areas result in a variety of age classes across the landscape. The large number of hardwood and conifer species allows this type to occupy many environments and locations. The general inaccessibility of these habitats have protected them from many of the human-induced disturbances such as intensive agricultural, residential and commercial development, grazing, and wood cutting. Montane hardwoods occur over a wide elevational range. Surrounding habitats include conifer-dominated types, chaparral types, blue oak and valley oak woodlands, and annual grasslands.

Physical Characteristics

Slopes range from gentle to steep. Soils are mostly rocky, coarse, and poorly developed. However, relatively large California black oak stands occur in mountain valleys on alluvial soils. Exposures tend to be south, west, and east, while conifers tend to dominant on northern exposures. Climates are typically Mediterranean but extremely variable given the wide distribution of this type. Average summer temperatures are moderate, while average winter temperatures range from near freezing to the mid-40's°F. Snow occurs in the winter at higher elevations, but does not remain as long as on adjacent conifer-dominated habitats.

SPATIAL AND TEMPORAL ASPECTS OF SUSTAINABILITY

Landscape-Level Sustainability

Over the long term, pollen analysis shows shifts in distribution of oak stands along altitudinal gradients. Approximately 10,000 years ago, oaks became a significant component of the Sierra Nevada montane forest according to pollen record analysis (Byrne et al. 1991). Prior to 10,000 years ago, persistent snowpacks into early summer may have minimized the importance of drought and caused dominance of dense coniferous forest types; fire seemed to be relatively rare from 12-10,000 years ago at these montane elevations. Increasing drought stress and more intense fires caused a relatively quick compositional change to a ponderosa pine-black oak woodland beginning 10,000 years ago; these open woodlands may have persisted from 10-5,000 years ago. During this period, the pollen record indicates that the oaks were associated with understory species which are characteristic of open, seasonally dry regions. Most of the oak trees located at the upper elevational limit of oaks were black oak and shrubs such as *Quercus vaccinifolia* (huckleberry oak). Roughly 5,000 years ago, oaks were replaced by pines and firs in the montane forest. The relatively larger existence of oaks in the Sierran montane forest from 10-5,000 years ago may be attributed to both more intense summer drought and increased fire intensity during this period at the montane forest elevation.

Viewed from a statewide scale, California's hardwood rangelands have decreased by over one million acres in the last 40 years (Bolsinger 1988). Major losses from 1945 through 1973 were from rangeland clearing for enhancement of forage production. Major losses since 1973 were from conversions to residential and industrial developments.

At a regional or watershed scale, certain parts of the hardwood rangelands have decreased due to rapid urban expansion (Doak 1989), firewood harvesting (Standiford et al. 1996), range improvement practices (Bolsinger 1988), and conversion to intensive agriculture (Mayer et al. 1985). This has caused increased fragmentation of habitat, increased conflicts between people with rural and urban value systems, predator problems, and soil and water erosion. No factor has had a more noticeable effect on shaping the oak community than urban development (Doak 1989). Urban expansion is most acute in the foothills of the Sierra, particularly from Nevada and Yuba counties southward to Fresno county. Blue oak and valley oak have been most affected (Holmes, 1990).The effect of spatial and temporal change on the acreage of hardwood rangeland habitat in the Sierra Nevada region are shown below in Table 3. Over a 40 year period, over 800,000 acres of hardwood land in the Sierra Nevada have been lost, representing almost 16 percent of the total acreage that existed 40 years ago.

Table 3. 40 year percent change in hardwood habitat by county in the Sierra Nevada region (from Bolsinger 1988).

County	40 yr. pct. change
Shasta	+7%
Tehama	-23%
Butte	-9%
Yuba	-18%
Nevada	-18%
Placer	-32%
Eldorado	+2%
Amador	-28%
Calaveras	-29%
Tuolumne	-42%
Mariposa	-21%
Madera	-13%
Fresno	-19%
Tulare	-2%
Kern	-15%
Sierra Totals	-16%

Oaks are desirable for firewood and have been harvested from hardwood rangelands for hundreds of years. Spanish missionaries were the first Europeans to harvest oak fuelwood. Gold and quicksilver miners later utilized oaks for shaft supports (Rossi 1980). By 1900, oaks were employed for commercial charcoal production and cleared for orchard plantations (Holmes 1990). Firewood harvest on hardwood rangelands (Doak and Stewart 1985) escalated in the mid-1970's, driven by high prices of alternative energy sources. Despite this trend, there was no historical assessment of the acreage and volume of firewood harvested on hardwood rangelands. To address the current impact of firewood harvest on hardwood rangelands, California Department of Forestry and Fire Protection personnel conducted annual aerial monitoring of firewood harvesting trends from 1988 through 1992. Surveyors estimated acreage, intensity, and location of harvest sites. Table 4 shows the compares the Sierra Nevada region to the entire state (Standiford et al. 1996). The aerial monitoring showed significant regional impacts from firewood harvesting in Shasta and Tehama counties. Although they have less than 10 percent of the state's hardwood rangeland, 50 percent of the total cords were harvested in these two counties (Standiford et al. 1996).

Table 4. General summary statistics of CDF aerial monitoring of firewood harvesting on hardwood rangelands over a 4-year period (Fall 1988 to Fall 1992).

Firewood Harvest Characteristics	Sierra Nevada Hardwood Rangelands	Total State Hardwood Rangelands
Estimated Cords Harvested	256,661	278,924
Acres	22,860	24,714
Precut crown cover	57%	58%
Postcut crown cover	17%	18%
Number of harvests	87	120
Annual percent acres harvested	0.12%	0.06%

Clearing oak woodlands for range improvement has historically altered the structure and extent of oak savannahs (Bartolome 1987). Mayer et al. (1985) attribute the decline in oak communities to "range modification" programs which usually involve conversion of the oak woodland to another vegetation type. Often this technique involved herbicides and controlled burning or mechanical removal, piling and burning to clear out the vegetation in order to reduce fire hazards or improve forage and watershed production (Holmes 1990). These practices have greatly reduced the distribution of oaks in northern California, particularly in the Sierra foothills (Rossi 1980).

Stand Level Sustainability Considerations

From the period 1932 to 1992, the canopy density and basal area of blue oak woodlands at the stand level has increased under typical livestock grazing practices, and fire exclusion policies (Holzman 1993). This indicates that if conversion does not occur, oak stands are fairly stable to increasing over a moderately long period, despite the publicized problem of lack of natural regeneration (Muick and Bartolome 1986; Bolsinger 1988; Swiecki and Bernhardt 1993). Holzman (1993) found that over the 60 year period of the study of blue oak communities in both the coast ranges and the Sierra Nevada foothills, mean oak basal area increased due to residual tree growth and recruitment of new individuals. The number of blue oak trees was stable or increased on most study sites. The quantity of foothill pine individuals significantly decreased while the number of interior live oak trees increased. At some sites interior live oak increased into the blue oak cover types suggesting that regionally the live oaks are encroaching into the deciduous oak communities. Despite this stand level stability, the most dramatic and significant alteration to the blue oak communities is the decrease of blue oak woodlands due to development. More than 20% of the plots in the blue oak study sites were converted to other land uses, primarily residential subdivisions (Holzman 1993).

In a study of 708 sites within the foothill woodlands, Davis (1995) quantified changes in tree cover and density of foothill woodland vegetation from 1940 to 1988 and found that: 1) on a statewide basis, tree and total woody cover in foothill woodlands seem relatively stable; 2) cover dynamics vary from site to site and do not reveal landscape level pattens except at large physiographic and climatic region levels; and 3) locally, woody cover is more dynamic than has been previously suggested. Tree cover increased at 45% of the sites and decreased at 42% of the sites. Tree cover decreased by more than 20% in 16% of the samples while tree cover increased by at least 12% in 17% of the sites. They conclude that decreases in tree cover at some sites is counterbalanced by increases at others. Thus, while large changes occur within individual sites, the overall cover of blue oaks remained relatively constant from 1940 to 1988. The authors caution, however, that the 48 year study interval may not be sufficiently long to detect the predicted decline in oak cover given present recruitment rates. An alternative explanation postulated by Davis (1995) is that blue oak demography is more dynamic than assumed; therefore, existing age and size structure information do not accurately predict future demographic changes.

Pollen analysis studies document the dynamics of hardwood rangeland composition over a very long-term period (Byrne et al. 1991). In general, hardwood rangelands showed a long-term period of relatively stable oak densities under the period of use by Native Americans. Following introduction of livestock grazing by Europeans, and clearing practices for intensive agriculture approximately 150 years ago, oak densities declined dramatically. Exotic annuals first show up in the pollen record at this same time. Since this initial exploitation of the oak resource in this early settlement period, oak cover on hardwood rangelands has increased dramatically. This is attributed to fire exclusion policies of the last 50 years, and the preponderance of low intensity, extensive management practices associated with ranching uses.

SUSTAINING ECOSYSTEM PROCESSES

With the introduction of domestic livestock and exotic annuals during the Spanish mission days, hardwood rangeland ecosystems have changed dramatically. The herbaceous layer has changed from a perennial layer to an annual layer (Crampton 1974). Fire intervals have increased dramatically and fire intensity has also increased (McClaren and Bartolome 1989). The overstory layer, if not converted to another land use, has generally increased (Holzman and Allen-Diaz 1991). Soil moisture late in the growing season has decreased, and bulk density has increased due compaction from higher herbivore densities (Gordon et al. 1989). Riparian zones are now less dense and diverse (Tietje et al. 1991). A general summary of the changes in ecosystem inputs from pre-settlement conditions to the current time are shown below (Table 5). The effect of these changes on ecosystem processes are discussed in more detail below.

Table 5. Comparison of Sierra Nevada oak woodland conditions before and after European settlement.

Pre-European Settlement Conditions	Changes in Ecosystems Inputs
Perennial herbaceous layer	Exotic annual invasion
Regular fire interval	Long fire interval and increase intensity
More open overstory layer	Overstory layer of unconverted stands has increased
Soil moisture higher, later into growing season	Soil moisture late in growing season decreased
Lower soil bulk density	Increased soil bulk density
Snags, large woody debris	Snags, woody debris cleaned up in typical management activities
Denser, more diverse riparian zone	Riparian zones less dense and diverse
Lower herbivore densities	Higher herbivore density, primarily domestic livestock

Herbaceous Composition

The pre-European herbaceous community consisted primarily of native perennial bunchgrasses such as purple stipa, pine blue-grass, blue wildrye, California brome, California melic, prairie junegress and California oatgrass (Crampton 1974). Perennial forbs such as Brodiaea and various legumes were also a part of the native oak community understory species (Holmes 1990). The native understory species were displaced by alien annuals from primarily Europe, Asia, Africa and South America upon the arrival of the European settlers. This displacement occurred in four distinct waves (Burcham 1970): 1) Wild Oat, 1845-1855; 2) Wild Barley and filaree, 1855-1870; 3) Yellow starthistle, bromes, other barleys, 1870; 4) medusahead, 1900. Soft chess, now the most widespread annual (Bartolome 1987) became abundant in the late 1890s.

Oak Canopy and Forage Production Processes

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 alter the nutrient status of the site because of the deep-rooting of of oaks and nutrient cycling from litter fall.

Oak removal was historically recommended as a means of increasing forage production on hardwood rangelands (George et al.). 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 percent 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 percent), there was a variable canopy effect on forage production (McClaren and Bartolome 1989a). Figure 1 shows how moderate blue oak canopy (50%) affects seasonal forage production in different rainfall areas of the state.

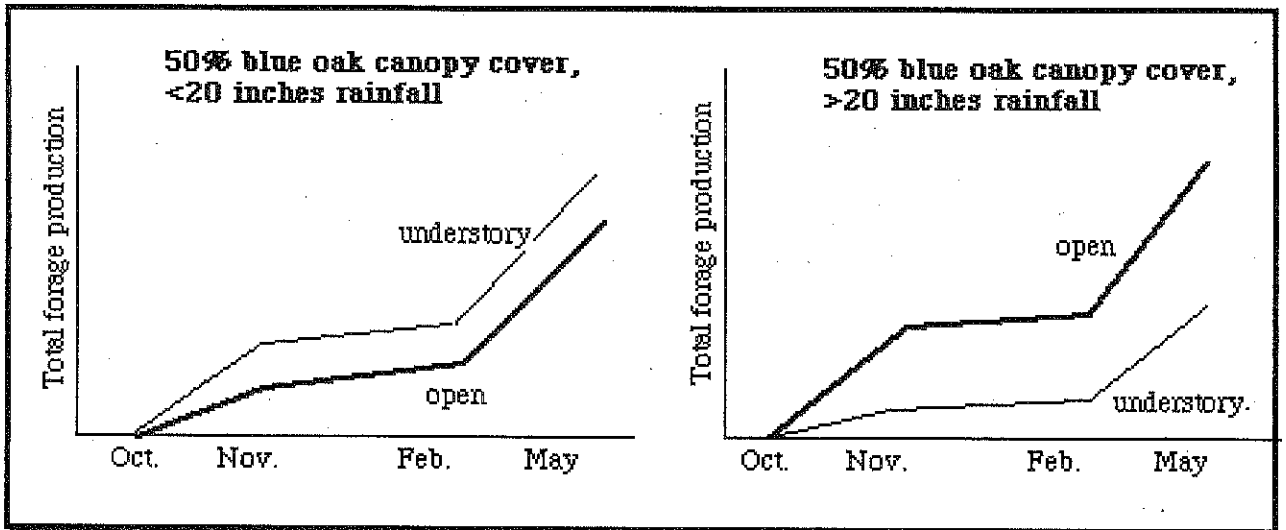

Figure 1. The effect of 50 percent blue oak canopy cover on seasonal forage production compared with open annual grasslands in two rainfall zones.

Blue oak, in the southern and central portion of its range, provides green forage earlier (with 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 which 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 percent canopy cover will have lower forage growth than cleared areas. One study in the Southern Sierra Nevada foothills, however, 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 6 below summarizes the results of research studies of the relationship between oak canopy and forage production.

Table 6. The effect of oak canopy on hardwood rangeland forage production (note: a "+" indicates that forage production is enhanced by oak canopy, and a "–" indicates that forage production is inhibited by oak canopy)

Species Group	Canopy Cover	Winter Forage Production	Spring Forage Production
Live oaks	Scattered (<10% cover)	– / +	– / +
	Sparse (10 - 25% cover)	– / +	– / +
	Moderate (25 - 60% cover)	–	–
	Dense (over 60% cover)	–	–
Deciduous oaks	Scattered (<10% cover)	+	+
	Sparse (10 - 25% cover)	+	+
	Moderate (25 - 60% cover)	– / +	– / +
	Dense (over 60% cover)	–	–

The increase in forage production beneath blue oak canopies, or in areas previously beneath blue oak canopies, is attributed, in part, to increased soil fertility due to 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 were removed. However, since the nutrient input from leaf liter ceases after tree removal, forage production increases will be temporary, until soil fertility gradually declines to similar levels as adjacent open areas. Long term studies have found 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, soft chess and ripgut brome. Clovers, annual fescues, filaree, soft chess, and foxtail fescue 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 of 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 percent will have the greatest effect on forage production;
- In areas thinned for forage enhancement, residual tree canopies of 25 to 35 percent are able to maintain soil fertility and wildlife habitat, and minimize erosion processes; and
- 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 different tree species canopy and in open grassland sites, Frost and Edinger (1991) found higher organic carbon levels, greater cation exchange capacity, lower bulk 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 under 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 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 store of nutrients in blue oak litter which is gradually depleted over time.

Comparison of soil moisture relationships in hardwood rangelands with perennial grasses has soil moisture until later in the growing season than hardwood rangelands with annual grasses (Gordon et al. 1989). This difference in soil moisture may at least partially explain some of the observed lack of sapling recruitment in oak woodlands. Evaluation of hardwood rangeland soil bulk density shows that areas with livestock grazing have a higher bulk 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.

Grazing Processes

Livestock grazing has had a major impact on the oak woodlands of California's Sierra Nevada. By 1880, Spanish coastal missions had acquired approximately four million sheep and nearly 1 million cattle (Holmes 1990) fostering a large demand for forage and oak browse. This high grazing demand has largely persisted, particularly affecting blue oak, black oak and valley oak. In addition to grazing by cattle and sheep, hogs and rodents have been important browsers of oaks. Feral hogs consume acorns while rodents such as ground squirrels and pocket gophers utilize large quantities of acorns and seedlings; this is perhaps due to removal of rodent predators and the introduction of food sources such as oats and filaree (Holmes 1990).

Grazing has both positive and negative effects on hardwood rangeland sustainability. Some of the positive effects of livestock grazing include:

- Reduced moisture competition between oaks and herbaceous material (Hall et al. 1992);
- Reduced transpirational surface area in seedlings, and 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;

- Fuel ladders are eliminated, reducing the probability of crown fires in grazed woodlands;

Some of the negative effects of livestock grazing are shown below:

- Livestock and other grazing animals consume oak seedlings and acorns (Swiecki and Bernhardt 1993; 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);
- Soil organic matter may be reduced.

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) 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, with excessive 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.

Deciduous oak regeneration was locally 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 1978). While seedlings become established, few develop into saplings. Live oaks, whose seedlings may be more resistant to grazing and browsing, have produced saplings with more success than have deciduous oaks 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 acorns and seedling damage by cattle, deer, rodents and insects (Griffin 1978).

According to demographic studies and experimental research, most extant blue oak populations are dominated by older individuals; current recruitment levels are insufficient to maintain the present distribution of blue oak (Davis 1995; Swiecki and Bernhardt 1993). Valley and blue oak are not regenerating in sufficient numbers to maintain existing stands (Muick and Bartolome 1986). 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 and Bernhardt 1993). Natural blue oak regeneration is thus a multiple step process which requires many years for completion. When grazing pressures and plant competition are minimal (such as along along roadsides beyond pastures) or where micro-habitat 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 differentially affect regeneration at different temporal stages of the recruitment process.

Swiecki and Bernhardt (1993) 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 dbh of 3 cm or less) were found on 15.3% of the plots; the majority of these grew from seedlings as opposed to sprouts 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 shows 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 and Bernhardt (1993) propose the following recommendations to enhance blue oak recruitment: 1) minimize understory shrub clearing in blue oak communities; 2) reduce the intensity and duration of browsing pressure on woody vegetation; 3) employ fire to manipulate understory vegetation so as to favor recruitment; 4) leave intact at least 20% overstory canopy cover within 0.1 ha unit of regeneration sites; 5) following gap creation, minimize livestock use until blue oak saplings are taller than browse level; 6) minimize "potentially adverse impacts" in sites near the limits of blue oak range.

Valley oak has experienced inadequate regeneration since the last century (Griffin 1973; Bernhardt and Swiecki 1991; and Danielsen and Halverson 1991). While seedlings establish, few develop into saplings. Alien annual grasses, which make less water available to oaks than 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 that a lack of sapling trees once suggested (McCreary et al. 1991; Standiford et al. 1996).

Figure 2 below shows a decision key for hardwood range landowners and managers to use to assess oak regeneration (Standiford and Tinnin 1996). This 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 this is consistent with the objective for the stand. Secondly, the health and vigor of the existing trees need to be assessed to determine if recruitment of small trees is needed to replace future tree mortality. Thirdly, the number of seedling and sapling trees should be evaluated. In areas with tree mortality, seedlings and saplings will be needed to replace tree mortality. When overstory tree density is below the desired level for management objectives, seedlings and sapling trees will be needed to increase tree density.

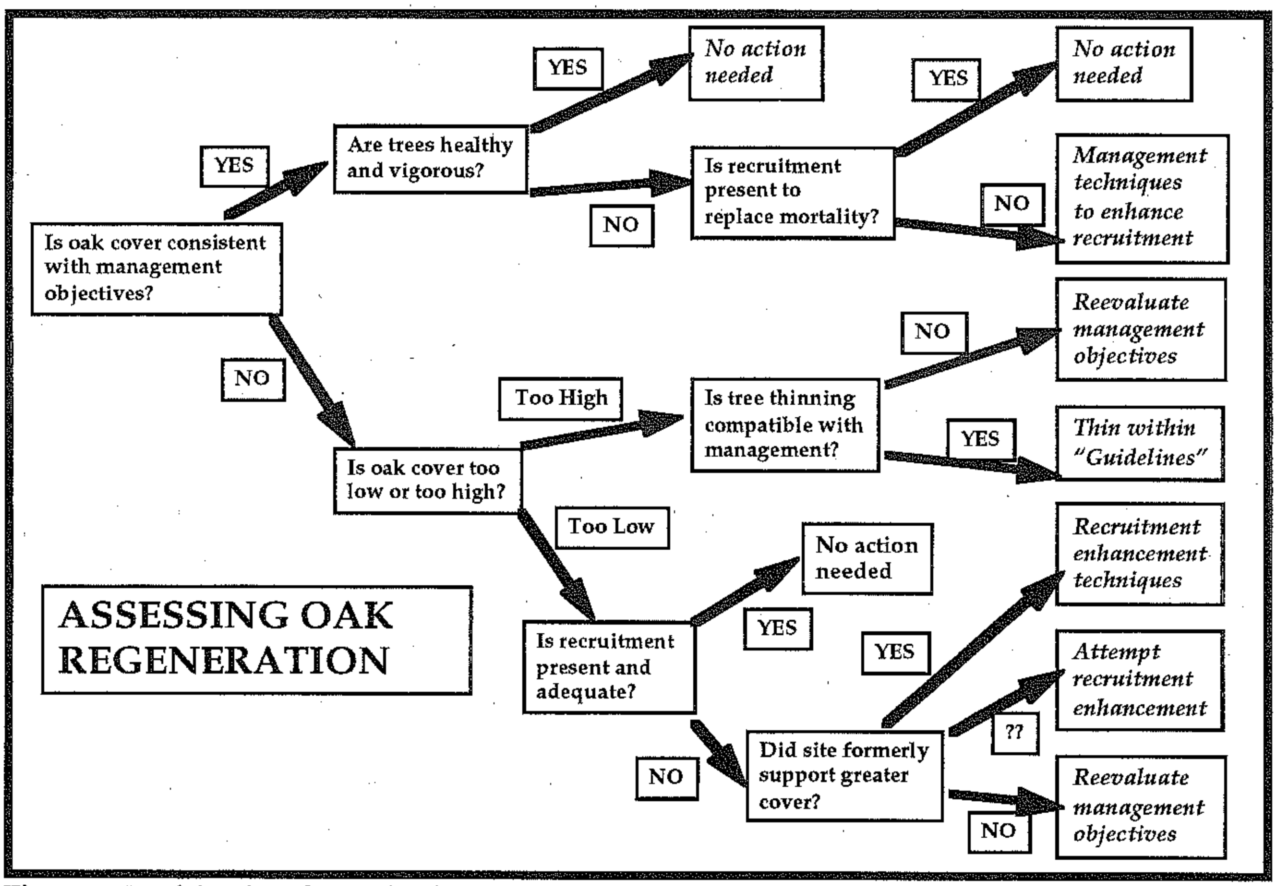

Figure 2. Decision key for evaluating oak regeneration on hardwood rangeland.

<u>Oak restoration and planting</u> (from McCreary 1996)

On areas that have been determined to have a "regeneration problem," it may be necessary to establish more oaks. Planting acorns or seedlings may be necessary where recruitment is inadequate to maintain oak cover on a long-term basis. However, the same factors which limit natural oak regeneration can make it difficult to successfully artificially regenerate native oaks. In general, substantial care must be taken to plant, protect and maintain young oaks in the field to ensure success. While there are many approaches for establishing oaks, the procedures described below have proved successful for a variety of oaks in a variety of environments.

<u>Direct Seeding Acorns</u>

Acorns should be collected fairly near the planting site, or from a very similar environment. Acorns can be collected directly from the trees or from the ground beneath. Generally, the healthiest acorns are those collected from the tree branches, since acorns that fall to the ground can dry out and be damaged - especially if they lie exposed for more than a few days during hot, dry weather. Acorns should be collected in early fall, when they begin to turn from green to brown and are starting to fall to the ground. Acorns should be placed in cold storage at temperatures just above freezing. Acorns collected from the trees can be placed directly in the refrigerator, while those collected from the ground should be soaked in water for several hours before storage. Those that float should be discarded.

Acorns can be directly planted from early November (after the first rains have soaked the soil) until early March. However, it's generally better to plant the acorns early in the season since research has shown that the earlier they are placed in the ground, the earlier they start to grow a root system. Plant the acorns one-half to one inch deep with the germinated root tip pointing down. Place ungerminated acorns on their sides in the holes and cover with soil.

Planting Seedlings

An alternative oak restoration effort is to use containerized or bare root seedlings. Seedlings are preferred in areas of high animal depredation on directly sown acorns. Seedlings may also give a substantial head start over directly sown acorns. However, seedlings are much more expensive to procure and plant. Containerized oak seedlings can also become "pot bound" if held too long. Seedlings should be planted between December and February, when the soil is wet, but not frozen.

Recent studies have shown that augering 1-2 foot holes below planting spots can help seedlings grow faster by breaking up hard, compacted ground and promoting deeper root development. Site preparation must include control of annual grasses and forbs using mulches, mechanical means, or herbicides. Placing a slow-release fertilizer tablet a few inches below and to the side of the root has increased initial seedling growth.

Riparian Management Processes

Although little of the state's water supply originates on hardwood rangelands in the Sierra Nevada, virtually all of it flows through riparian zones on hardwood rangelands (CDF 1988). Also, most of the state's major reservoirs are located on hardwood rangelands. Riparian zones provide important habitat for wildlife and aquatic organisms. Hardwood rangeland management has an impact on water quality and wildlife and fisheries habitat. Little basic research has been completed on the hydrological processes on hardwood rangelands, although several studies in the Sierra Nevada been initiated (IHRMP 1994). It has been shown that removal of up to one-third of the oak canopy has little effect on water quality and yield in one regional study (Epifanio et al. 1991). New efforts have been started to develop rangeland management practices to minimize erosion as part of the state's water quality management plan (Humiston 1995).

Fire Ecology Processes

Fire is a natural part of California's oak woodland ecosystem as well as an important management tool since Native Americans first inhabited these areas. Fire plays a role in the development of oak woodland stand structure, oak regeneration processes, the development of habitat for wildlife, nutrient cycling, and economic uses of oak woodlands for domestic livestock. The ecological effects of fire will vary depending on the frequency of fires, the season and intensity of the fires, and the size of patches that occur from fire-induced mortality of mature trees. Adjacent vegetation types, such as chaparral and montane forests, influence fire effects in oak woodlands. Recent increases in the acreage of stand destroying fires in oak woodlands resulting from decades of attempting to exclude fire from our wildland areas, points to our need to develop strategies in which fire is included in management activities in order 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 most woodland oak species have the capacity for young seedlings and saplings 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 burning by Native Americans 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. Surveys 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 prescribed burning until the 1950s. At that time, the use of fire in oak woodlands declined, driven 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.

One of the few studies of fire frequency on Sierra Nevada hardwood rangelands was carried out by McClaren and Bartolome (1989) in Central Sierra oak woodlands. Figure 3 shows the fire history in one sample area at the University of California's Sierra Foothill Research and Extension Center. Fire frequency in these foothill oak forests was around 25 years prior to settlement by Europeans in the mid-1800s. After settlement by Europeans, the use of fire as a management tool can be observed, with a fire frequency of about every 7 years. No fires were observed from 1950 until the mid-1980s, when fire suppression was the dominant practice.

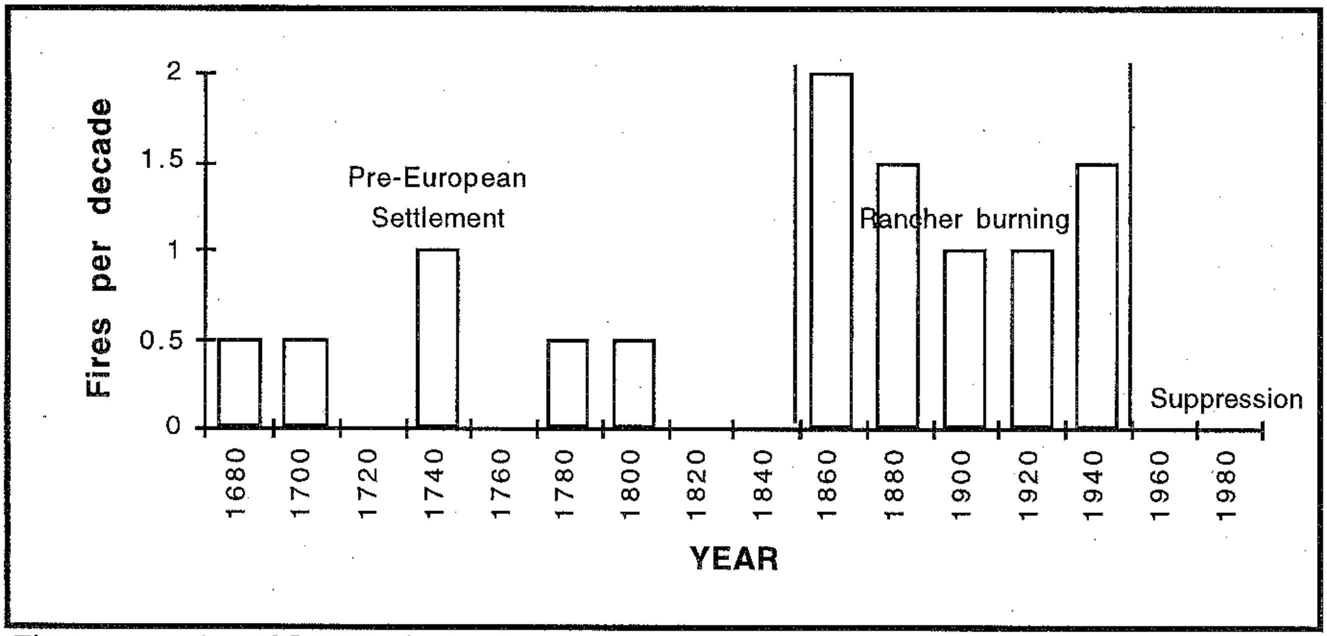

Figure 3. Number of fires per decade for a sample blue oak stand at the Sierra Foothill Research and Extension Center -- 1680 to 1983.

Effects of Fire On Oak Woodland Sustainability

Higher fire frequencies in the past may have created conditions more conducive for oak regeneration. McClaren and Bartolome (1989) compared oak stand age structure 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 in the 1880s to 1940s. Oak recruitment has been rare since fire suppression.

The factors leading to enhanced oak regeneration from higher fire frequencies are not entirely clear. Allen-Diaz and Bartolome (1992) looked at blue oak seedling establishment and mortality with the treatments of grazing and prescribed burning in coastal areas of hardwood rangelands. Neither of these treatments significantly affected oak seedling density nor the probability of mortality when compared to unburned and ungrazed areas, suggesting that seedling establishment is compatible with grazing and fire.

Perhaps the importance of fire on oak regeneration is explained by the enhanced postfire oak sprout growth documented by Bartolome and McClaren (1989). 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 kills diseases and pests, such as the Filbert Weevil (*Cucurlio occidentalis*) and the Filbert Worm (*Melissopus latiferreanus*), which can infest the acorn crop (Lewis 1991). Fire also 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 2000 plant species; and an estimated 5000 species of insects. Figure 4 graphically shows the diversity of vertebrate wildlife species predicted for each of the five major hardwood rangeland habitat types (including coastal oak woodlands). The management and long-term sustainability of California's hardwood rangeland habitats will best be served if ecological components and their inter-relationships are recognized and addressed by owners and managers.

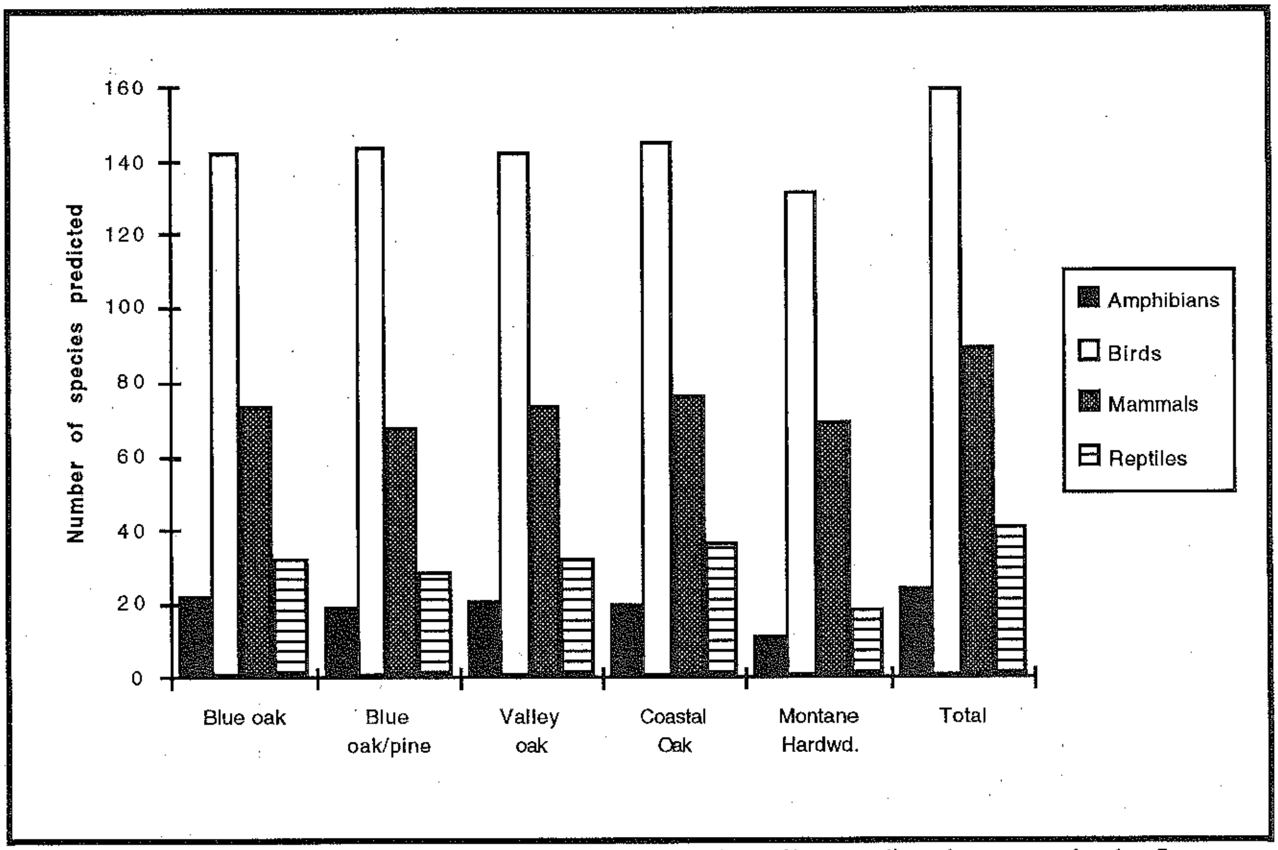

Figure 4. Numbers of amphibians, birds, mammals, and reptiles predicted to occur in the five California hardwood rangeland habitats by Version 5.0 of the California Wildlife Habitat Relationships System (CWHR). This list only includes those species in the CWHR System that are predicted to use one or more tree size and canopy cover classes for breeding, feeding, and/or cover.

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. Oak woodlands provide habitat for many wildlife species which depend on the oak trees, shrubs, grasses, forbs, seeds, fruits, insects and other components of the oak woodland system. Much of the wildlife diversity is directly related to the vegetation diversity of trees, shrubs, logs, leaf litter, grasses, forbs and other habitat components (Block 1990). Changes 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 3 year study of non-game 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 which bred elsewhere, 17 breeding species which 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 the Sierra oak woodlands. For example, Hutton's vireo, orange-crowned warbler, and Wilson's warbler are closely associated with interior live oak. Birds such as the white-breasted nuthatch and western bluebird 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 and 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, pinyon mouse, deer mouse, dusky-footed woodrats and ornate shrews. They found low numbers of small mammals in their study sites and hypothesized that the indictment of small mammals as a major cause of poor white oak regeneration is premature.

Block and Morrison (1990) found one amphibian species (the California slender salamander) and three reptile species (the western fence lizard, western skink and the southern alligator lizard) 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 are 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. Figure 5 gives the relative number of wildlife species that are predicted to use various elements found on hardwood rangelands.

Riparian habitat elements are used by almost 90 percent 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 include these trees as well as trees in various stages of vigor in order to maintain critical wildlife habitat (Block and Morrison 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).

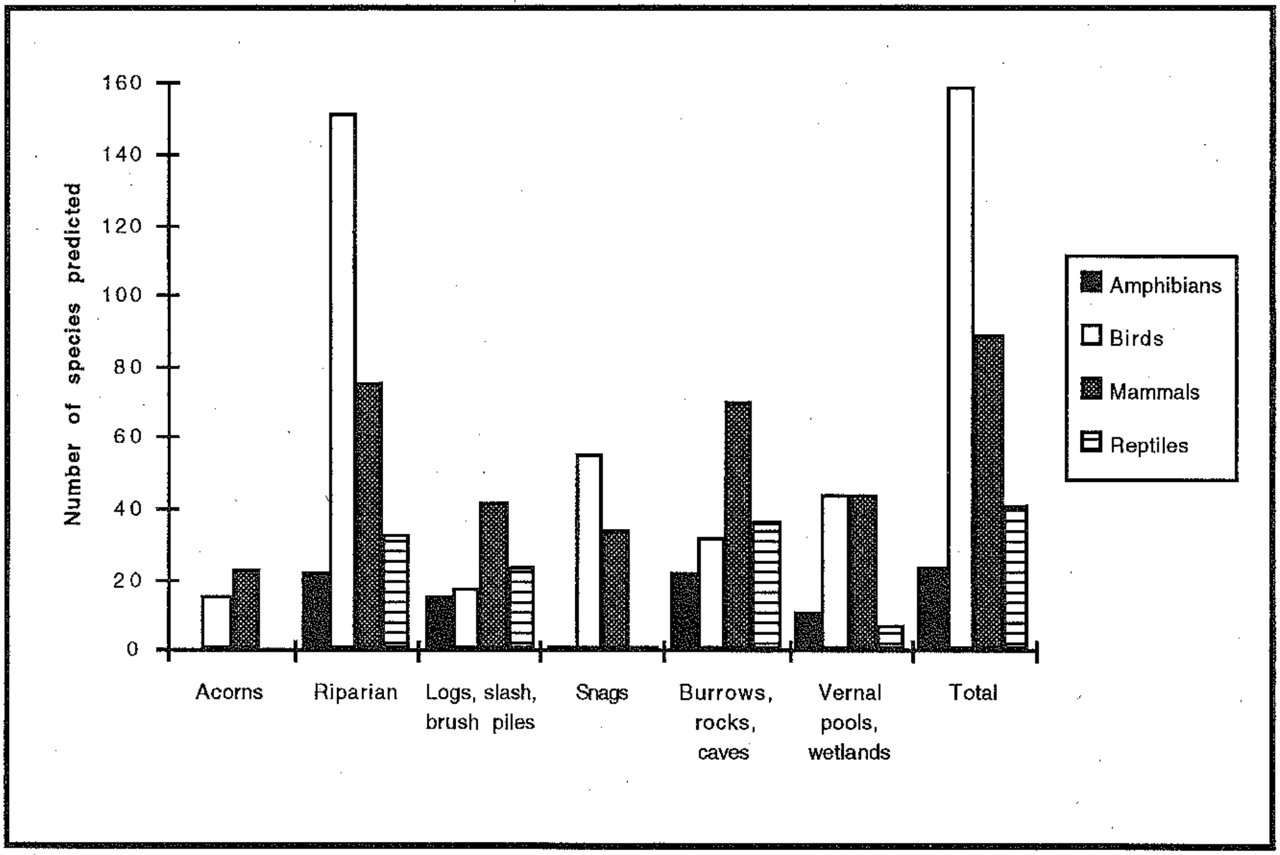

Figure 5. Number of amphibians, birds, mammals, and reptiles predicted to use several important habitat elements of California hardwood rangeland habitats by Version 5.0 of the California Wildlife Habitat Relationships System (CWHR). This list includes those species in the CWHR System that are predicted to use one or more of these elements for breeding, feeding, and/or cover.

With this background on factors influencing biodiversity on hardwood rangelands, and the spatial and temporal trends for these habitats, the threats to continued high biodiversity 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).

MAINTAIN ECONOMIC VIABILITY AND UTILIZATION OF HARDWOOD RANGELANDS

Hardwood rangelands have been important to humans living in the Sierra Nevada for centuries. For the most part, traditional management practices utilized by Native Americans and then by the ranching community, were able to maintain large blocks of habitat that supported ecosystem processes at a variety of scales. Recent trends in human use, however, is leading to conversion of lands to residential and industrial uses as people leave the major urban areas of the state to seek the aesthetic and amenity values of hardwood rangelands. Some of the economic and utilization issues facing hardwood rangelands in the Sierra Nevada are discussed below.

Stewardship by Native Americans

The original human inhabitants of Sierra Nevada hardwood rangelands were Native Americans. Acorns were the dietary staple and sustained their cultures that lived among the oak woodlands (Pavlik et al. 1991). Virtually all tribes west of the Sierra harvested acorns for food. Acorns are estimated to have been the primary diet for more than 3/4 of all Native Americans in California; black oak was the preferred species in many regions (McCarthy 1993). Each tribe had special mechanisms for acorn gathering, storing, hulling, drying leaching, pounding and cooking. The bark roots, wood, small branches and galls of oaks were also utilized.

Acorns were second to salt among the most frequently traded foods among Native Americans. The trade in acorns flowed from west to east with, for example, Miwoks gathering black oak acorns from the western Sierra and trading with the Mono Lake Paiute for pinyon pine nuts (Pavlik et al. 1991); trading across elevational zones was also common (McCarthy 1993). Territorial claims of tribes, villages, families and individuals were often based on the distribution of acorn-producing oak groves. The finding that many cultural traditions and celebrations focused on the oaks attests to the central role oaks played in their lives. Aside from providing sustenance and goods for barter, oaks and acorns were also employed as medicines and dyes.

The use of fire and burning was the most prevalent and effective management tool native Californian people utilized to manage the oaks and the acorn crop (McCarthy 1993). Low-intensity fires were also used to promote oak growth while avoiding damage from high intensity fires, and helped keep prized oaks from being dominated by conifer species. Many village sites were found to be located near mature black oak stands

Economic Viability of Hardwood Rangelands

Since the 1800s, hardwood rangelands in the Sierra Nevada have been used mainly for domestic livestock products. Dramatic annual fluctuations in livestock markets, coupled with risk from forage shortages due to high variability in annual rainfall, has made many livestock operations marginal. Figure 6 shows the range of fluctuation for several of these factors (Doak and Stewart 1986; USDA various years). Another risk to maintenance of extensively managed livestock operations are the high opportunity cost from suburban developments or intensive agricultural products such as wine grapes. Uncertainty about federal grazing policies, where many hardwood rangeland operators lease summer forage, also hinders economic viability of hardwood rangeland enterprises. Low profitability and high risk has accelerated conversion of extensively managed private ranches to suburban developments.

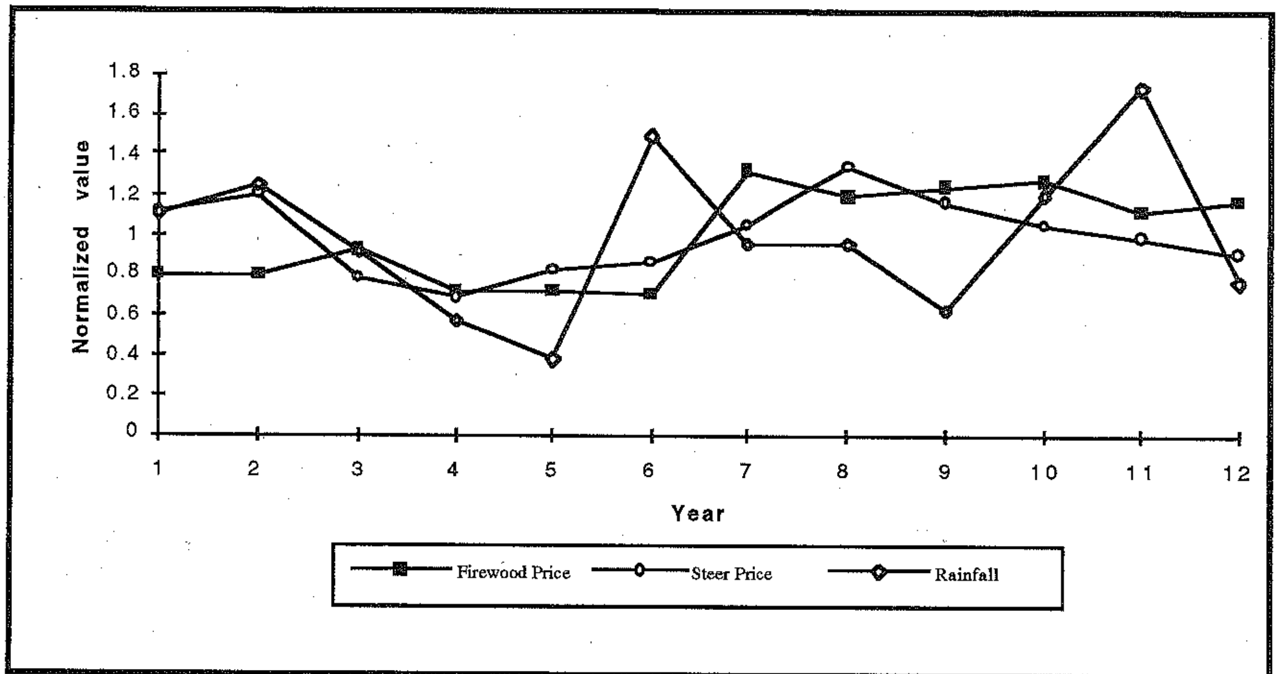

Figure 6. 12 year trends in steer and firewood prices, and annual rainfall, for a southern Sierra Nevada hardwood rangeland area (lines are normalized, so that 1.0 is the mean value over the 12 year period).

Traditional efforts to increase profitability of hardwood rangelands have focused almost exclusively on enhancing forage production through removal of the oaks. This simplification of the ranch ecosystems did pay short term dividends in improved forage yields, but the same risk from fluctuating product markets and weather variability continued to make ranching a low profitability enterprise.

New markets have developed in the last 20 years for the oak trees on hardwood rangelands for firewood and as habitat for commercial hunting enterprises. This diversified economic portfolio has helped to enhance the economic sustainability of hardwood rangelands by spreading risk out over several enterprises, increasing overall returns per acre, and providing an economic incentive to conserve more diverse hardwood rangeland ownerships.

A study was initiated to study the effects of these new markets for firewood and hunting on hardwood rangelands (Standiford and Howitt 1990; Standiford and Howitt 1993). Firewood production, livestock production, and commercial hunting were incorporated into a multi-product objective function to model the optimal oak canopy levels of hardwood range owners over time.

Effect of hunting on total financial return

Total ranch profitability is one of the most important factors impacting conversion of hardwood rangelands to subdivisions and other more urbanized uses of the resource, and away from the large expanses of extensively managed open space that characterizes most hardwood range operations. The hypothesis is that hunting and firewood harvesting offers a broadened market base for hardwood range managers and improved economic returns to the land, which may help to reduce conversions.

Figure 7 shows the net present value per acre (NPV) over a 12 year period for a hardwood range site with 750 cubic feet per acre. This figure shows the major impact that hunting has on the total economic value of hardwood range management. On a poor forage-producing site, NPV is increased by 142 percent with hunting (from $51 to $123 per acre), and hunting is the dominant economic value on the site. On a high quality forage-producing site, hunting increases the NPV by 59 percent (from $138 to $221 per acre), although cattle production remains the dominant economic value on this site. This figure shows the relatively minor contribution that firewood harvesting makes to the total economic value of the operation.

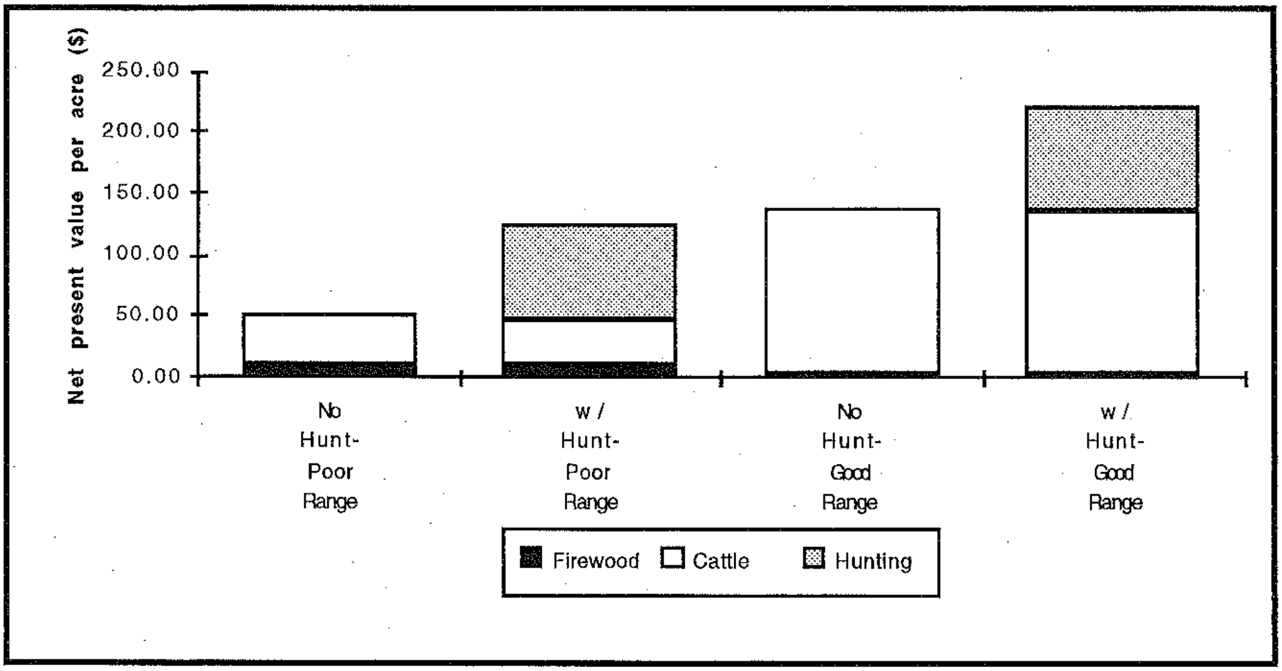

Figure 7. Effect of hunting on net present value of a 1000 acre hardwood rangeland site with 750 cubic feet per acre, and poor forage-producing capacity (poor range) or high forage-producing capacity (good range).

Effecting of hunting on firewood harvest

Figure 8 shows the cumulative firewood harvest over a 12 year period on a low productivity range site. Less oak firewood harvesting occurs when hunting value is received. This indicates that the marginal decrease in hunting revenue due to oak canopy changes is greater than the marginal revenue from the firewood harvest. Hunting apparently provides an incentive for hardwood range managers to conserve oak trees. The optimum decision is for no firewood harvesting to occur over a on areas with less than 500 cubic feet per acre of oak wood volume (about 6 cords). The marginal cost of harvesting firewood exceeds the market price at these levels. This is consistent with the low levels of firewood harvesting reported above. Ranch managers are not likely to completely clear their oaks for forage enhancement because the marginal revenue of the added forage is less than the marginal cost of cutting trees.

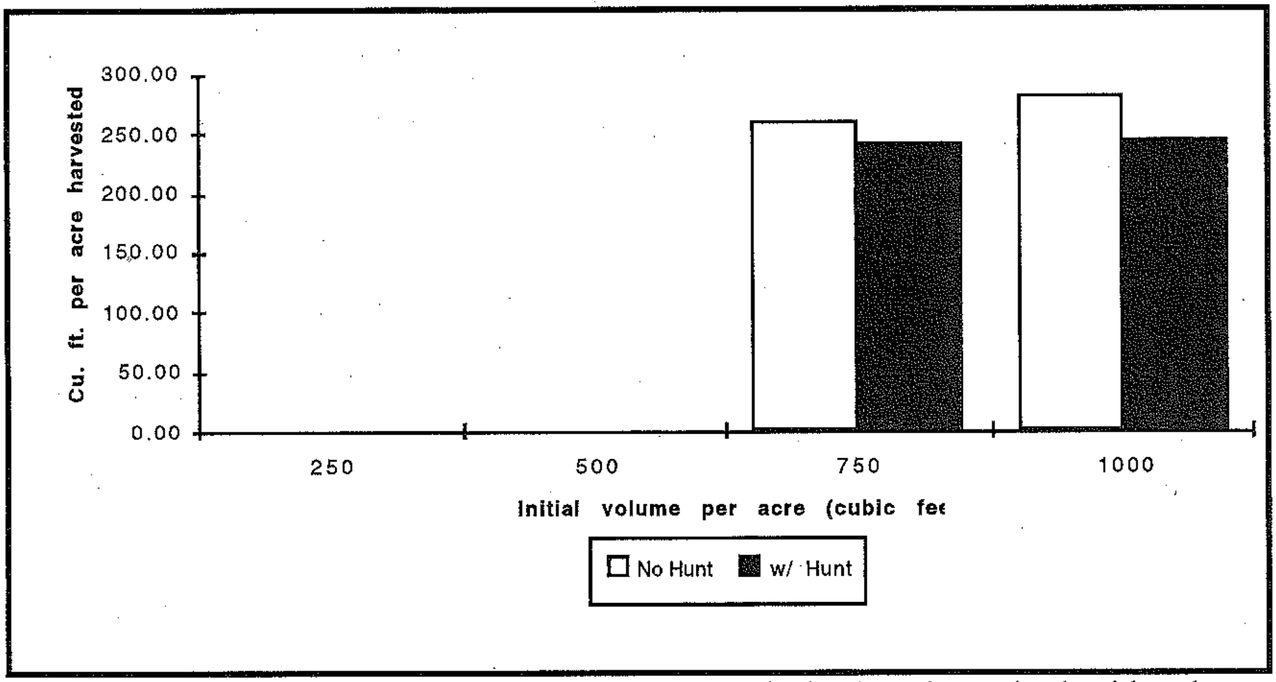

Figure 8. Predicted total firewood harvested over 12 years for hardwood rangelands with and without hunting enterprises.

Effect of Hunting on Livestock Density

Figure 9 shows the optimum number of cow-calf pairs on a 1000 acre hardwood rangeland parcel with oak crown canopy cover levels ranging from 25 to 80 percent. As crown cover increases, livestock density decreases. Livestock density is lower on areas with hunting, due to allocation of some of the forage base to wildlife species, and also labor and management constraints. Decreased livestock use helps reduce risk from fluctuating livestock markets and poor forage years, and may relieve pressure on important resources such as oak regeneration and riparian zones.

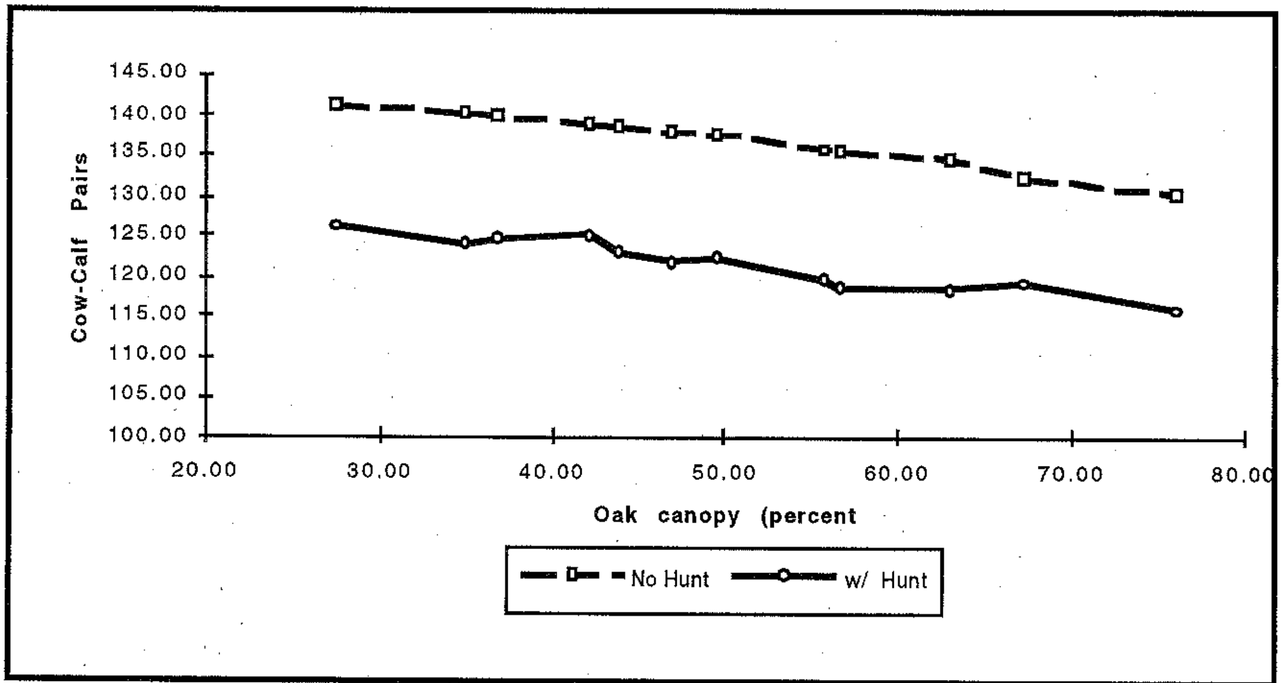

Figure 9. Effect of oak canopy cover and commercial hunting enterprises on optimum cow-calf pairs on a 1000 acre hardwood rangeland parcel.

Interest in hardwood rangeland conservation raises the question as to whether current private markets will provide adequate oak cover to meet perceived public needs. With new markets for recreational hunting on private lands, preliminary results indicate that these markets may provide some incentive for hardwood rangeland managers to reduce tree harvesting levels. This research indicates that it is unlikely that any level of firewood harvesting will occur on oak stands with low volumes per acre. The hunting enterprise reduces intensity of livestock use, decreasing pressure to enhance the forage base with tree harvest. There is no economic incentive to clear dense oak stands for improvement for livestock use based on the current range of revenues and costs.

New Markets

Wood Products and Specialty Forest Products

Throughout history, rangeland hardwoods have been utilized for fuelwood. The spreading, highly-branched tree form of most rangeland hardwoods creates numerous grain deviations making them a low quality tree for other wood products by standard log and lumber grading rules. There are numerous limitations to the utilization of rangeland hardwoods for other wood products (Shelly et al. 1996):

- low proportion of stem to branch wood,
- unknown or poorly understood wood properties, and
- unproven product performance.

Little scientific research has been performed on the wood properties of most California hardwood species because of the lack of a strong commercial interest. The exceptions are California black oak, tanoak and madrone. These are primarily timberland species but they can also be found in some rangeland regions. In certain situations, rangeland hardwoods may be a viable resource for local needs or specialty products. Availability and quality concerns make it unlikely that any rangeland hardwoods could supply a commodity market; however, based on wood properties and characteristics, successful niche markets are possible. Local products made by artisans, woodworkers and hobbyists prove that high value products can be made, however special manufacturing techniques and innovative marketing strategies may be required to do it economically.

Hardwood forests are also a resource for many products that are not primarily based on processing the wood. Numerous enterprises have developed across the country that are based on gathering plant materials from the forest for a wide variety of uses. Several examples of collected materials that have found established markets are:

- Wild mushrooms
- Berries and wild fruit
- Acorns, nuts, and seeds
- Decorative branches and other plant materials for floral displays
- Bark, leaves, and roots for flavoring, medicinal, or pharmaceutical uses
- Wild plants for nursery stock
- Basket making and weaving supplies
- Plant materials for natural dyes

Typical characteristics of these enterprises are that they are usually small, labor intensive, cottage industries with few equipment needs and low capital costs. All forms of marketing can be found, from roadside stands, direct sales to wholesale/retail vendors, or to catalog ventures.

Markets for Amenity Values

Historically, the market value of hardwood rangelands for subdivision near urban areas has exceeded their value for amenities and ecological functions. The recent human population increase in hardwood rangelands, however, has raised the potential values of woodland amenities to a point where they are often a financially viable alternative to land development (Scott 1996). Landowners may find that woodland conservation provides the best financial scenario, especially if they own woodlands with high conservation value. However, land owners outside of the suburban fringe may find that their properties are not increasing in development potential and are unlikely to be considered woodland open space.

Woodlands provide a large component of the quality-of-life sought by many relocating industries, and the relatively low cost of industrial sites in these woodlands is equally appealing. Woodland owners along the wildland urban interface often find that their management options track public demand for specific values. If woodland conversions trigger a public demand for amenity protection, the solutions typically must be found on private lands. Open space easements, and other deed restrictions provide financial, tax, or development incentives for the voluntary maintenance of public amenity values on private lands.

CONSERVATION POLICY ISSUES

A series of policy instruments to conserve hardwood rangelands have evolved in California and throughout the Sierra Nevada region against the backdrop of the ecological and economic factors described above. A variety of interest groups have expressed concerns about oak woodlands to the California State Board of Forestry (BOF), the state regulatory and policy-making body responsible for forest and rangelands. Three incidents hastened the development of a state hardwood policy by the BOF (IHRMP 1992): 1) Monterey and Santa Clara counties petitioned the BOF to classify oaks as commercial species regulated under the Forest Practice Act because of concerns over hardwood harvesting; 2) a 1,000 acre Timber Harvest Plan (THP) in the Northern Sierra requested removal of most black oaks in a critical migratory deer corridor; and 3) the increase in the number of new biomass power plants had the possibility of severely impacting hardwoods on commercial and non-commercial lands. In response to these issues, the BOF asked the University of California (UC), the California Department of Forestry and Fire Protection (CDF), and the California Department of Fish and Game (CDF&G) to develop a program of research, education, and monitoring on conservation of hardwood rangelands (Passof and Bartolome 1985). This program is known as the Integrated Hardwood Range Management Program (IHRMP).

With the development of the IHRMP, the BOF adopted a *Resolution on Hardwoods* on February 3, 1987. This resolution concluded that although the BOF had the authority and obligation under the Forest Practice Act (California Legislature 1980) to protect the hardwood resource, it was premature to declare hardwoods "commercial," which would immediately invoke Forest Practice Act regulations on hardwood rangelands. An intensive educational program, problem-focused research, and frequent monitoring of the resource was felt to be the most effective way to work with landowners and local governments to resolve hardwood issues. The IHRMP was the mechanism expected to accomplish the goals of this non-regulatory program. This policy has continued up to the present.

The IHRMP's mission is stated as follows:

> *"To maintain, and where possible expand, the acreage of California's hardwood range resource to provide wildlife habitat, recreational opportunities, wood and livestock products, high quality water supply, and aesthetic value."*

The initial goals and direction of the IHRMP were driven by statewide concerns about regeneration, wildlife habitat, and conversion pressure (IHRMP 1988), and were focused at a stand or single property level. As understanding of the ecological processes on these lands have increased, IHRMP goals have broadened to include multi-ownership, landscape level considerations (IHRMP 1992). The current goals of the IHRMP are to:

- Develop methods to sustain hardwood rangeland ecosystems and landscapes;
- Maintain wildlife habitat on hardwood rangelands;
- Restore degraded hardwood rangelands;
- Ensure land use planning uses available information to conserve hardwood rangeland ecosystems;
- Maintain economically viable hardwood rangelands;
- Maintain statewide information base about trends, conditions, and extent of hardwood rangelands; and
- Help focus public awareness about the importance of hardwood rangeland habitats

The IHRMP has funded 66 research studies over ten years, which in turn has stimulated additional research on various aspects of hardwood rangelands. Specific areas investigated with IHRMP funding include: oak regeneration (20 projects); wildlife habitat (11 projects); soil, water and land use issues (10 projects); hardwood rangeland management strategies (10 projects); and monitoring trends and status of hardwood rangelands (15 projects). This research has been conducted by investigators in UC, the California State University, private universities, and private research and consulting firms. These research studies, resulting in over 150 new scientific articles, contribute to the base of understanding of the ecological and managerial processes extent on hardwood rangelands (IHRMP 1992). Research results have been disseminated in IHRMP-sponsored symposia and workshops and incorporated directly into educational documents and newsletters.

An important aspect of the development of educational programs is to characterize the demographics of the various audiences that have on impact on hardwood rangelands (Huntsinger and Fortmann 1990; McClaran and Bartolome 1985; Day 1987; Pillsbury and Oxford 1987; Whittington and Tietje 1993). A wide variety of educational programs have been developed for the diverse audiences affecting hardwood rangelands.

Surveys were implemented to evaluate the effectiveness of education as a conservation policy. A survey comparing participants in IHRMP educational program to the population at large showed that ranchers, resource managers, conservation groups, and consultants, though diverse, have a strong set of shared values (Stewart 1991). Natural beauty and maintenance of wildlife diversity were the two most important values of hardwood rangelands to all audiences surveyed. Cooperative Extension (CE) has had some contact regarding oak woodland issues with 49 percent of the ranchers in the state, and 69 percent of the resource managers. Of those who attended various IHRMP educational workshops, 74 percent of the ranchers and 70 percent of the resource managers had some follow-up discussions with CE about oaks. Individuals who participated in IHRMP educational programs were more likely to carry out oak enhancing management activities than non-participants.

The attitudes and management practices of hardwood rangeland owners were evaluated in 1985, just prior to the intensive educational outreach of the IHRMP (Huntsinger and Fortmann 1990). This same survey was repeated in 1992 to discern trends that resulted from the expanded educational programs (Huntsinger 1992). This showed that 18 percent of hardwood rangeland properties had been sold in the seven year period, indicating that education must be an on-going process because of high ownership turnover. Livestock grazing was still the dominant hardwood range land use after seven years, occurring on 67 percent of all acres. The percentage of large parcel owners relying on livestock grazing as their major source of income declined from 70 percent in 1985 to 50 percent in 1992. Following the seven year period of intensive educational outreach, oaks were more valued by landowners for wildlife habitat, soil protection, enhancement of property values, and for browse and mast production. The number of large owners selling firewood decreased from 40 percent in 1985 to 23 percent in 1992. The number of large landowners who cut living trees for forage enhancement declined from 58 percent in 1985 to 38 percent in the seven year period. During this same time period, the number of owners who conducted wildlife habitat improvements increased from 56 percent of the large landowners to 64 percent. Owners who received advice from CE or other public advisory services were more likely to carry out oak promoting practices (protect sprouts, maintain fixed oak canopy levels, thin softwoods to promote oak growth, planting oaks). Strong attitudes against regulation of hardwood rangelands continued in the majority of all ownership classes.

Local Policy Initiatives

In May, 1993, the BOF held hardwood hearings to evaluate the effectiveness of seven years of research and education as an approach to hardwood rangeland conservation. These hearings showed strong support for the continuation of research, outreach, and monitoring, and revealed a high diversity of threats facing hardwood rangelands throughout the state. Within the Sierra Nevada region, firewood harvesting was recognized to be a concern only in the northern Sacramento Valley, while conversion to subdivisions was important in the central Sierra Nevada (IHRMP 1994). These findings confirmed that statewide regulations would not be able to effectively address the wide diversity of conservation issues. The BOF decided to intensify its outreach to local governments, and encourage their participation in local policy development with the assistance of the IHRMP. Following a period of outreach, the Board will evaluate progress by local governments in providing policies which protect hardwood rangelands, and determine where statewide policies might be needed to address continuing problems.

The IHRMP has worked closely with local governments to encourage the development of local policies to conserve hardwood rangelands. Within the Sierra Nevada region, 13 of the 15 counties have adopted or started the process of adopting local hardwood rangeland conservation strategies in response to the BOF resolution. The strategies followed fall into three general categories, namely: county voluntary guidelines; land use planning; and tree harvesting ordinances. Table 7 describes the type of county policy for the Sierra Nevada region. Each of these are discussed below.

County Voluntary Guidelines

At the 1993 BOF Hardwood Hearings, Tehama County political and agricultural leaders volunteered to initiate a broad-based effort to address concerns about widespread firewood harvest on hardwood rangelands in their county. This resulted in the appointment of a county oak committee composed of various resource agencies, environmental groups, and agricultural groups. They developed a set of voluntary oak retention guidelines to maintain economic viability of grazing and ecological values of hardwood rangelands. This set of guidelines was passed by the county Board of Supervisors, and mailed to all landowners in the county (Gaertner 1995). With this county effort as a successful pilot project, several other counties began to develop voluntary guidelines. There are currently 10 counties in the Sierra Nevada region in various stages of developing voluntary guidelines. The leadership for drafting guidelines varied in different areas, and included the local chapter of the California Cattleman's Association, the County Board of Supervisors, the County Planning Department, the Agricultural Commissioner's Office, and the Resource Conservation District. Each effort addresses important local issues, and include education and monitoring. For example, several of the voluntary guidelines in the northern Sacramento Valley addressed impacts from firewood harvest, while biomass harvest, fire protection, and soil erosion were important issues addressed in southern Sierra guidelines. Most of the guidelines also have general recommendations on urban development patterns.

General Planning Process

The county General Plan sets policies governing land use. The California Oak Foundation, working with the BOF, put together sample language on the importance of oak woodlands for the General Plan and mailed this to all county planning departments. Only three counties in the Sierra Nevada are using some part of the land use planning process to address oak conservation issues. This approach has been more widely used in the Central Coast and southern California regions of the state. (Tietje and Berlund 1995). Within the Sierra Nevada, Tuolumne County has an especially innovative open space conservation strategy, in which they prioritize various habitats, and establish priorities for maintaining open space on the basis of the relative sensitivity of the habitat in the county. Landscape-based goals are established to link open space habitats together through corridors (Peck 1993)

Ordinances

Only one county in the Sierra Nevada region has utilized a tree ordinance as a mechanism to protect oaks. Ordinances create a regulatory environment at the county or city level, and usually involve a permitting process for the removal of any tree over a certain size class, and mitigation standards where tree removal is allowed. Tree ordinances are more common in Bay Area and Southern California counties. Most tree ordinances have focused on the single tree rather than at a broad habitat scale. CDF has developed an educational book on tree ordinances which describes the importance of setting objectives for an area prior to writing an ordinance, and monitoring whether the objectives have been accomplished (Bernhardt and Swiecki 1991). This book has been distributed to all counties in the state.

Table 7. Type of county hardwood rangeland policy being developed in the Sierra Nevada region.

Sierra Nevada County	Voluntary Guidelines	Ordinances	Land Use Planning Process
Shasta	x		
Tehama	x		
Butte	x		
Yuba			
Nevada			
Placer		x	
Eldorado			x
Amador	x		
Calaveras	x		
Tuolumne	x		x
Mariposa	x		
Madera	x		
Fresno	x		
Tulare			x
Kern	x		

Conclusion

Important information has been developed on the ecology and sustainable management of hardwood rangelands through activities of the IHRMP. Sociological and biological monitoring shows that diverse audiences have accepted and acted on educational information. A large number of counties have started the process of adopting local conservation strategies to conserve hardwood rangelands. It is quite clear, that education and research have played a major role in conserving hardwood rangelands. Major accomplishments have been made in the more rural areas of the state, where livestock and natural resource management are the predominant land use. Where individual landowners have the ability to implement management activities that affect large acreages, education and research has contributed to decisions that favor conservation of hardwood rangelands.

However, for much of the Sierra Nevada region, conversion of hardwood rangelands to urban or suburban land use is having the largest impact on sustainability of resource values. Educational materials developed on hardwood rangeland conservation in land use planning have been widely accepted by professionals working in the land use arena. However, very little progress has been made in incorporating these educational materials into successful land use plans adopted by the county government. Since conversion to residential and industrial uses is ultimately is a land use decision, it is a political process involving action by elected officials with input from different constituencies. The political and economic forces vary greatly in different parts of the Sierra Nevada. Since "success" in this area involves multiple individuals agreeing on a political course of action, this issue will present the largest challenge for a research and education strategy. It needs to be evaluated very carefully over the next several years to determine if education and research alone are sufficient to sustain the ecological values of hardwood rangelands.

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