Wildlife

Gen. Tech. Rep. PSW-100. Berkeley, CA. Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1987.

The Importance of Hardwood Habitats for Wildlife in California[1]

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Recent analyses of the variety of wildlife species that find optimum or suitable conditions for breeding in different habitat types in California show that hardwood types rank among the most important in the State. For example, Ohmann and Mayer (1987) report that more terrestrial vertebrate species in California breed in conifer and hardwood habitats than in any other types. These two general habitat types support breeding by approximately equal numbers of amphibians, reptiles, and mammals, but the hardwood types have more breeding birds than any other general habitat. Similarly, Verner (in press) showed that "oak woodlands rank among the top three habitat types in the number of bird species for which they provide primary breeding habitat." In a recent search of the Statewide file on Wildlife-Habitat Relationships managed by the California Department of Fish and Game, Mayer (1986) found that 13 species--1 amphibian, 4 mammals, and 8 birds--find conditions suitable for reproduction only in hardwood-dominated ecosystems, including riparian types. These patterns are even more significant when combined with the fact that approximately 20 percent of California's land base supports hardwoods.

Given the knowledge of the need for hardwood habitats by wildlife, one must wonder why the critical needs of wildlife species using these habitats have been so little studied. For example, what are specific dependencies of most species of wildlife on hardwoods? Many species consume mast when available, and many nest in cavities in the trees, but would these species be threatened by the loss of the hardwoods? Managers have no reasonable guidelines for retention of hardwoods for most wildlife species, in terms of tree size or age, basal area, canopy cover, or dispersion. And what are normal, annual fluctuations in abundance for any terrestrial vertebrate that breeds regularly in hardwood habitats in California?

The following are among the more critical research needs: (1) standardized methods for studying the habitat relationships of wildlife, particularly for distinguishing among habitat use, preference, and-need; (2) implementation of standardized monitoring programs to measure trends in wildlife populations; (3) better Habitat Suitability Index (HSI) models as used in the Habitat Evaluation Procedures (U.S. Dept. Int., Fish and Wildlife Serv. 1980), including verification for specific localities; (4) more accurate Wildlife-Habitat Relationships (WHR) models of the sort used by the USDA Forest Service (Verner and Boss 1980); (5) better models of plant succession for predicting changes in plant species composition over time; and (6) an understanding of the effects of habitat fragmentation on wildlife species, particularly the mosaic of different habitat types as embodied in the new and growing discipline of landscape ecology (e.g., Picket and White 1985).

This section of the proceedings on wildlife will not go far in answering the needs identified above, but it will provide some direction. In addition, several studies currently underway promise, within the next 5 years, major advances in understanding of several aspects of the habitat relationships of wildlife in hardwoods. Finally, I see additional reason for optimism in the growing awareness among managers of the need to include wildlife considerations when planning for the future of California's hardwood resources.

[1]Presented at the Symposium on Multiple-Use Management of California's Hardwood Resources, November 12-14, 1986, San Luis Obispo, California.

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Gen. Tech. Rep. PSW-100. Berkeley, CA. Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1987.

Conceptual Framework and Ecological Considerations for the Study of Birds in Oak Woodlands[1]

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Abstract: The distributions and abundances of birds within oak woodland communities of California are the results of geologic events leading to the formation of the Mediterranean-type ecosystem, and of more recent anthropogenic impacts that have altered the landscape. These human-wrought disturbances to oak woodlands likely are affecting population parameters and distributions of birds throughout California. Because little is known of bird-habitat relationships in oak communities, however, the actual effects of these land-use practices on birds are unknown. Here we present a framework for the study of birds in the oak woodlands of California. The principal objective of this framework is to outline aspects of bird biology, ecology and behavior that must be addressed before assessments of habitat quality can be made. Assessments of habitat quality require that population numbers, reproduction rates, and survival rates be monitored. Further, bird habitats must be studied to determine site characteristics of areas that birds actually use within oak woodlands. Determination of specific patterns of resource use entails intensive study of bird activities. Collection of all of these data requires extensive field work to determine temporal and spatial patterns of habitat and resource use. There are no shortcuts for obtaining this information.

The distributions, abundances, and habitat-use patterns of birds in oak habitats are influenced by numerous factors. Avian settlement patterns and processes of speciation can be traced to the Tertiary and Quaternary periods. During these periods climatic changes, mountain building, and glaciation resulted in the present distributions of hardwoods throughout the state of California, which have in turn strongly influenced the distributions of birds (Hubbard 1973, Axelrod 1977). Proximate and ultimate factors, biotic and abiotic processes, temporal and spatial patterns, and various innate and learned behaviors interacted to shape the patterns of habitat use evident in modern species. Recent anthropogenic pressures have reshaped the landscape and have altered the environments available to birds. These changes have most likely altered the historic habitat-use patterns of birds.

Unfortunately, little is known of bird-habitat relationships in oak woodlands. Early naturalists (e.g., Grinnell and Miller 1944, Leopold 1951, Miller 1951) provided valuable species accounts based on their observations. The information presented by these naturalists was generally in the form of qualitative descriptions of species' distributions and habitat associations. These data are of insufficient detail, however, to allow resource managers to assess habitat quality or to predict the effects of environmental change on bird population parameters. Further, Muick and Bartolome (1985) found few recent studies of bird-habitat relationships in oak woodlands. Consequently, a research program is required to study bird-habitat relationships in oak woodlands that provides information in sufficient detail to allow assessments of habitat quality and predictions of the effects of habitat change on birds.

The purpose of this paper is to present a general framework for the study of birds in oak woodlands. Our primary objective is to outline aspects of bird biology and ecology that researchers must study to provide the baseline information required by managers to determine habitat quality for birds. We begin this framework by suggesting a scenario to describe distributional patterns of birds within oak woodlands. We use the discussion as a basis for explaining ecological and behavioral relationships of birds to their environments, and we conclude by presenting a methodology for the study of birds in oak woodlands.

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DISTRIBUTIONAL PATTERNS

Geologic Evolution of Oak Woodland Ecosystems

The evolution of the contemporary Mediterranean ecosystem and associated oak woodlands consisted of an ever-changing environment that enabled biotic speciation to occur. Changing climatic conditions during the Tertiary, and periods of extensive glaciation and mountain building during the Quaternary, strongly influenced patterns of extinction and speciation of both plant and animal life. Axelrod (1973, 1977) developed a theory for the evolution of oak communities based on paleobotanical evidence. That theory suggested that oak diversity decreased as the geographic range of oaks constricted with time from the Miocene through the Pleistocene. Axelrod's theory appears to be consistent with those of avian speciation presented by Rand (1948), Selander (1965), Mengel (1970), and Hubbard (1973). Changing landscapes during the Tertiary and Quaternary periods likely resulted in varying environmental conditions (e.g., temperature, moisture) for different species of birds. As the total area occupied by oaks decreased with time, less habitat was available for many birds. Further, decreases in floristic and structural diversity probably led to a decrease in bird species diversity. Previous studies (MacArthur and MacArthur 1961, Cody 1974, Tomoff 1974) demonstrated that bird species diversity was positively associated with structural vegetative diversity. Others (Robinson and Holmes 1984, Rotenberry 1985) noted that many birds appeared to selectively use plant species. Consequently, as plant species diversity decreased with time, a concomitant decrease in bird species diversity likely occurred.

These influences and the selective processes of isolation and restricted gene flow during Pleistocene periods of glaciation were largely responsible for extinctions and speciations of birds (Rand 1948, Selander 1965, Hubbard 1973, Diamond 1984). Selander (1965) noted that about 30 percent of the species that occurred during the Pleistocene are now extinct. Although most of the evolutionary processes leading to existing taxa of birds probably occurred during the Miocene and Pliocene (Wetmore 1951), evolution during the Pleistocene continued to differentiate species on subspecific and semi-specific levels (Rand 1948, Selander 1965). Hubbard (1973) traced speciation within the genera *Pipilo* (towhees), *Toxostoma* (thrashers), *Callipepla* (quail), and others as having occurred during the glacial periods of the Pleistocene. He further postulated that many of the species that arose during the Pleistocene had a tendency towards sedentariness. Given this limited motility, these species may be the ones least likely to escape the effects of environmental change.

Human Impact on Oak Woodlands

The evolution of oak-woodland communities occurred over millions of years. More recently, humans have exerted artificial, selective forces that have further altered distributional patterns of oaks. Prior to European settlement, aborigines burned the understory of oak woodlands. These periodic burns influenced the population structure of oaks, and consequently the structure and floristic composition of the stands (Jepson 1910, Rossi 1980). Since European settlement of western North America, changes to oak communities by humans have been more dramatic. Early Spanish settlers cleared expanses of oaks for livestock and agriculture. Increased grazing pressures with the introduction of domestic livestock probably further altered the population structure of oak stands because of the consumption of acorns and seedlings by sheep and cattle. The introduction of livestock also indirectly changed the composition of the understory as many exotic annual grasses displaced natural perennials. Recent fire-suppression programs have allowed conifers to displace oaks as Bonnicksen and Stone (1982) noted for the Sierra Nevada. Bartolome (pers. commun.) speculated that oaks in California are becoming less diverse and proportionally more sclerophyllous owing to historical grazing and cutting practices. He attributed this trend to the tendency of live oaks to sprout after being cut, and to the resistance of live oaks to browsing. In contrast, many of the white oaks [e.g., valley oak (*Quercus lobata*), blue oak (*Q. douglasii*), and Engelmann oak (*Q. engelmannii*)] are not regenerating well, and seedlings and saplings are more heavily impacted by browsing. Thus, the trend described by Bartolome has led to a decrease in white oak populations whereas live oak populations have remained relatively stable.

The cumulative impact of these disturbances has resulted in younger, smaller stands with altered age structures and species compositions. The effects of such large-scale habitat modifications on birds are not well known. However, birds that require extensive stands of large trees or birds that rely on blue, valley or Engelmann oak might be affected adversely by these changes in age and stand structure. Consequently, it is imperative that a protocol be established for the study of birds in oak woodlands. Only through detailed study of these relationships will there be sufficient information to assess environmental impacts on the avifauna of the California oaks and to develop methods to retard or mitigate these losses if judged unacceptable.

STUDY OF ECOLOGICAL RELATIONSHIPS OF BIRDS

Before questions regarding the effects of oak management practices on birds can be addressed, it is necessary to understand the basic biologies, ecologies, and behaviors of birds found in oak woodlands. Whether or not a bird "selects" a given habitat is attributable to a number of proximate and ultimate factors (Hilden 1965, Cody 1985). Proximate factors are cues that induce a bird to settle in a certain area. Examples of proximate factors are song posts, nest sites, and the composition and structure of vegetation. Ultimate factors are those that provide conditions for reproduction and survival. As such, ultimate factors are adaptations resulting from the processes of natural selection. Thus, the study of bird-habitat relationships in oak woodlands is essentially the study of proximate and ultimate factors that allow birds to settle, reproduce, and survive within oak habitats.

Because habitat selection by birds is largely behavioral (Morse 1980), investigators often take indirect approaches to discern patterns of habitat and resource use. These approaches include monitoring population parameters, characteristics of bird habitats, and resource abundances. Measures of population parameters are required to understand the viability of species in relation to habitat conditions (Van Horne 1983). Detailed quantitative descriptions of macro- and microhabitats of species are needed by resource managers to determine habitat quality (Capen 1981). It is also necessary to measure resource abundance--in particular prey abundance--and relate these measures to bird population parameters to more fully understand the extrinsic factors that regulate bird distributions and abundances. We detail below parameters that should be included in the study of birds in oak woodlands.

Study Areas

In our discussion we present examples from the Tejon Ranch, Kern County, California and Blodgett Forest Research Station (University of California, Berkeley), El Dorado County, California. The Tejon Ranch is a 100,000-ha corporate landholding in the Tehachapi Mountains. Approximately 35,000 ha of the Ranch are oak woodlands dominated by blue oak, valley oak, and California black oak (*Quercus kelloggii*), with lesser amounts of canyon live oak (*Q. chrysolepis*), interior live oak (*Q. wizlisneii*), and Brewer's oak (*Q. garryana* var. *brewerii*). The Ranch is managed for multiple uses including livestock production, firewood cutting, and game hunting. Cutting of oaks is restricted to selected stands of blue, valley, and black oaks, leaving large areas of the Ranch uncut. Elevation on the Ranch ranges from 1,000 to 1,700 m, and aspects include all directions. Because of the variety of land-use practices that occur on the Ranch, it provides an excellent opportunity for study of the effects of oak removal and livestock grazing on bird habitat.

Blodgett Forest Research Station is located in the central Sierra Nevada at an elevation of 1300 m. Vegetation of the forest is characteristic of mixed-conifer forests of the Sierra Nevada, and is dominated by white fir (*Abies concolor*), Douglas-fir (*Pseudotsuga menziesii*), sugar pine (*Pinus lambertiana*), ponderosa pine (*Pinus ponderosa*), incense-cedar (*Calocedrus decurrens*), and California black oak. Tanoak (*Lithocarpus densiflorus*), Pacific madrone (*Arbutus menziesii*), and golden chinquapin (*Castanopsis chysophylla*) are major hardwood components of the subcanopy. The 1,200-ha forest is divided into compartments 5-35 ha in size. Compartments have been subjected to various forest management practices. Thus, Blodgett affords an opportunity to study the use of hardwoods by birds within a managed mixed-conifer forest.

Methods

Monitoring Populations

Although monitoring population parameters of species is time- and labor-intensive, these data are integral to understanding bird-habitat relationships in oak woodlands. Commonly, only species abundances are measured by researchers. Van Horne (1983) discussed the shortcomings of this approach and showed that population abundance alone may be an inadequate measure of habitat quality. Whether or not a habitat is suitable for a species depends largely on the species' ability to survive and/or reproduce there. Thus a population-monitoring program should not only be directed at estimating abundances, but it should also attempt to estimate rates of survival and reproduction.

Numerous techniques are used to measure the numbers of birds (Ralph and Scott 1981, Verner 1985). No technique, however, has been shown to yield accurate estimates of bird numbers, as all techniques contain inherent biases. Counting birds can provide measures of absolute abundance or indexes of relative abundance. We will not review the advantages and disadvantages of the various techniques because these have been reviewed amply elsewhere (Ralph and Scott 1981, Verner 1985, Verner and Ritter 1985). It is important to note, however, that the choice of counting technique depends on several factors and should not be haphazard. Further, comparisons of abundances using most methods should be restricted to the same species, location, and season (J. Verner, pers. commun.).

We used the variable-radius circular plot method (Reynolds and others 1980, Verner and Ritter 1985) to estimate numbers of birds at the Tejon Ranch. Eighty points were placed at 300-m intervals using a systematic-random sampling design. We chose 300-m intervals to ensure sampling independence among points. Censusing was done by only one observer to remove observer differences. The observer remained at the point for 5 min and recorded all birds detected by sight or sound. Counts were replicated at each point three times. Censuses were done between 05:30 and 09:30 from 29 May to 24 June 1986. We used a Fourier series estimator from the computer program TRANSECT to calculate density estimates (Laake and others 1979). We calculated densities only for species for which we accumulated >40 detections. Density estimates ranged from 4.8/40 ha (Nuttall's woodpecker), to 47.2/40 ha (plain titmouse) (table 1). Coefficients of variation ranged from 3.8 percent (acorn woodpecker) to 20.9 percent (northern flicker) (table 1). Although we cannot evaluate the accuracy of these density estimates, the shapes of the probability density functions met the shape criterion of Burnham and others (1980), and the coefficients of variation for most of the density estimates were less than 20 percent, suggesting that the estimates were within ranges of precision generally accepted by wildlife biologists.

Estimates of bird numbers generally have been restricted to the breeding season under the assumption that the breeding season is the most important in a bird's life history. The breeding season is not the only time of the year when oaks are used by birds, however. Many species are year-long residents, and others may use an area during nonbreeding periods as short-term migrants or as wintering birds. If birds change their patterns of resource use, then studies restricted to the summer may not detect shifts in some critical aspects of resource use. Consequently, use of oaks by nonbreeding birds might be as important for their ultimate survival as the oaks are for the survival of breeding birds. Lack (1954) and Wiens (1977) noted that the nonbreeding season might be the most critical period of a bird's annual cycle. Consequently, it is critical that bird numbers are monitored throughout the year and not only during the breeding season.

As an example of the temporal variation in avifaunal composition, we recorded the species present in the oak woodlands of the Tejon Ranch from 14 to 20 April 1986 and from 18 May to 20 June 1986. Although there was extensive overlap of the species present during both periods, we recorded 13 species during April that were not present during May and June, and 9 species detected during May and June were not detected during April (table 1). Most of the species detected only during April were probably migrants (with exception of California condor) which used Tejon Ranch woodlands as foraging and resting sites. The species detected in May-June but not during April were probably late-arriving breeding birds. Thus, if surveys or censuses were restricted to only one of these periods, many species would have gone undetected. These data are only preliminary, but they serve as examples of the dilemma faced by resource managers attempting to construct bird-habitat models: different sets of species use a particular area during different seasons. Further, if habitat-use patterns by birds change over time, then changes to the environment might differentially affect the species present during different times. An increasing body of literature indicates that different tree species are differentially preferred by birds based on the season (Travis 1977, Conner 1980, Hutto 1981, Morrison and others 1985). In New Hampshire, for example, Kilham (1970) showed that in winter downy woodpeckers (*Picoides pubescens*) were attracted to birches (*Betula papyifera*) that were infested with a scale insect. Therefore, managers must provide adequate habitat for a variety of situations.

Many studies of bird populations are restricted to estimating densities during a single year. Wiens (1981), however, cautioned against single-sample surveys because the numbers estimated during any one year may not be representative of long-term population trends. Fretwell and Lucus (1970) and Van Horne (1983) noted that once the preferred habitat of a species becomes saturated, the surplus population will occupy marginal habitats. Theoretically, the relative densities of the species in marginal habitats may exceed the numbers found in superior habitats, leading to erroneous conclusions if population densities alone are used to index habitat quality. A more appropriate method for monitoring habitat quality must include estimates of reproduction and survival rates for species found in the oak woodlands, as well as numbers. Further, the monitoring program should occur over a timeframe encompassing temporal variations in population parameters in response to various biotic and abiotic factors.

Study of Habitats

Descriptions of bird habitats are central to the study of birds in oak woodlands. The study of habitats involves two major steps. The first step is to associate birds with macrohabitats such as blue-oak savanna or canyon-live-oak woodlands. These general associations have been provided by early naturalists (e.g., Grinnell and Miller 1944, Leopold 1951, Miller 1951); Verner (1980) summarized regional associations. These descriptions provide useful summaries and serve to narrow the range of possible hardwood communities where a species might be found. Much of the information provided by these naturalists is used to construct models of wildlife-habitat relationships. These wildlife-habitat models are matrices that qualitatively rate the suitability of various seral stages of common vegetation types for selected species of wildlife. Because these models are based mostly on general descriptions, many existing models of wildlife-habitat relationship have been found to be inaccurate when tested with empirical data (Dedon and others 1986). Further, the descriptions of habitats and distributions provided by these models are only very general in nature. For instance, a blue oak stand may exhibit certain structural or floristic characteristics that are used disproportionately

Table 1. Species of birds present within the oak woodlands of the Tejon Ranch during the 1986 breeding season. Estimates of the densities (#/40 ha) given for common species.

Species	Presence Status[1]	Density[2] n	D	pct CV
California condor (*Gymnogyps californianus*)	1			
Cooper's hawk (*Accipiter cooperii*)	3			
Red-tailed hawk (*Buteo jamaicensis*)	3	45	7.7	18.5
Golden eagle (*Aquila chrysaetos*)	3			
American kestrel (*Falco sparverius*)	3	9		
California quail (*Callipepla californica*)	3	38		
Mountain quail (*Oreortyx pictus*)	3	10		
Band-tailed pigeon (*Columba fasciata*)	3			
Mourning dove (*Zenaida macroura*)	3	263	20.1	7.5
Western screech owl (*Otus kennicottii*)	3			
Great-horned owl (*Bubo virginianus*)	3			
Northern Pygmy-owl (*Glaucidium gnoma*)	3	1		
Long-eared owl (*Asio otus*)	3	1		
Anna's hummingbird (*Calypte anna*)	3	26		
Acorn woodpecker (*Melanerpes formicivorus*)	3	1120	39.6	3.8
Lewis' woodpecker (*Melanerpes lewis*)	1			
Nuttall's woodpecker (*Picoides nuttallii*)	3	55	4.8	15.3
Hairy woodpecker (*Picoides villosus*)	2	4		
Northern flicker (*Colaptes auratus*)	3	49	11.7	20.9
Olive-sided flycatcher (*Contopus borealis*)	2	1		
Western wood-peewee (*Contopus sordidulus*)	2	111	13.8	10.3
Dusky flycatcher (*Empidonax oberholseri*)	1			
Black phoebe (*Sayornis nigricans*)	2			
Say's phoebe (*Sayornis saya*)	1			
Ash-throated flycatcher (*Myiarchus cinerascens*)	3	244	30.3	11.0
Western kingbird (*Tyrannus verticalis*)	3	11		
Purple marten (*Progne subis*)	2	1		
Violet-green swallow (*Tachycineta thalassina*)	3	226	33.6	8.6
Stellar's jay (*Cyanocitta cristata*)	3			

Table 1. Continued.

Species	Presence Status[1]	Density[2] n	D	pct CV
Scrub jay (*Aphelocoma coerulescens*)	3	195	22.4	11.4
Common raven (*Corvus corax*)	3	5		
Plain titmouse (*Parus inornatus*)	3	346	47.2	8.6
Bushtit (*Psaltriparus minimus*)	3	5		
White-breasted nuthatch (*Sitta carolinensis*)	3	174	28.0	8.3
Brown creeper (*Certhia americana*)	2	1		
Bewick's wren (*Thryomanes bewickii*)	1			
House wren (*Troglodytes aedon*)	3	348	44.2	8.3
Blue-gray gnatcatcher (*Polioptila caerulea*)	3	8		
Western bluebird (*Sialia mexicana*)	3	34		
American robin (*Turdus migratorius*)	3	25		
Phainopepla (*Phainopepla nitens*)	2	1		
Loggerhead shrike (*Lanius ludovicianus*)	1			
European starling (*Sturnus vulgaris*)	3	46	18.5	19.1
Hutton's vireo (*Vireo huttoni*)	1			
Warbling vireo (*Vireo gilvus*)	1			
Yellow-rumped warbler (*Dendroica coronata*)	3	3		
Townsend's warbler (*Dendroica townsendi*)	1			
Hermit warbler (*Dendroica occidentalis*)	1			
Western tanager (*Piranga ludoviciana*)	2	1		
Black-headed grosbeak (*Pheucticus melanocephalus*)	3	130	19.9	13.6
Rufous-sided towhee (*Pipilo erythrophthalmus*)	3	7		
Brown towhee (*Pipilo fuscus*)	3	99	24.7	14.9
Chipping sparrow (*Spizella passerina*)	3	10		
Lark sparrow (*Chondestes grammacus*)	3	2		
Golden-crowned sparrow (*Zonotrichia atricapilla*)	1			
White-crowned sparrow (*Zonotrichia leucophrys*)	1			
Dark-eyed junco (*Junco hyemalis*)	3	1		
Red-winged blackbird (*Agelarus phoenueus*)	3	5		

Table 1. Continued.

		Density[2]		
		n	D	pct CV
Western meadowlark (*Sturnella neglecta*)	3	22		
Brewer's blackbird (*Euphagus cyanocephalus*)	3	11		
Brown-headed cowbird (*Molothrus ater*)	3	8		
Northern oriole (*Icterus galbula*)	3	221	35.1	8.2
Purple finch (*Carpodacus purpureus*)	1			
House finch (*Carpodacus mexicanus*)	3	76	15.8	15.5
Lesser goldfinch (*Carduelis psaltria*)	3			
Lawrence's goldfinch (*Carduelis lawrencei*)	2	147	27.7	18.0

[1] 1-detected only between 14 and 20 April; 2-detected only between 18 May and 20 June; 3-detected both between 14-20 April period and 18 May-20 June.

[2] n = number of detections; D = density (1//40 ha) estimates; pct CV = percent coefficient of variation. All densities calculated using Fourier series estimator from the computer program TRANSECT.

by a species. Thus it is instructive to examine in more detail aspects of the areas a species actually uses (i.e., microhabitat) within the macrohabitat where it is found. Microhabitat includes the size and shape of leaves, branches, bark, and other subtle features of the vegetation present in the macrohabitat. These features vary with the size and age of the tree, for example. Thus, the density--or even mere presence--of a bird may be related not only to the plant species present, but their size, shape, and vigor. The failure of existing wildlife-habitat models to incorporate these fine-scaled aspects of species' microhabitats may be one reason why the models perform poorly.

Two primary techniques are used to describe the microhabitats of species. One method correlates the abundance of a species to combinations of physiognomic and floristic characteristics. This method entails estimating relative or absolute numbers of a species at a set of fixed census points and correlating these abundances to physiognomic and floristic characteristics measured at the points. Morrison and others (1987) used stepwise multiple regression (Draper and Smith 1981) to relate relative abundances of species to habitat characteristics. They used fixed-radius circular plots to obtain indexes of relative abundance, and measured habitat characteristics within the radius of the census plot. Thus, if a species is strongly associated with certain habitat features and those features are measured by the investigator, this method is potentially effective. Other investigators use variable-radius circular plots to census birds. However, the area over which these birds are recorded can be greater than the area within a fixed-radius plot, and thus may contain greater habitat heterogeneity. Thus using regression techniques to discern relationships between a species and habitat components might yield weaker associations than using fixed-radius plots because the species might not be closely associated with the location where the habitat measurements were taken.

An alternative method of quantifying habitats is to center habitat plots at the locations where birds are found. Larson and Bock (1986) found that organism-centered plots provided better descriptions of a species' habitat than using the regression techniques described above. There could be little question as to whether or not the bird was associated with the habitat, because by definition habitat is where the organism is found. There is a risk, however, that only the more conspicuous members of a population will be sampled by this method. This effect might be lessened if the observer moves slowly through the area, using care not to disrupt bird activity patterns. Separate plots could be centered at locations used for perching, singing, foraging or nesting. Collins (1981) showed that the characteristics of areas used by a species for different purposes (e.g., nest sites vs. perch sites) may differ. The strength of this type of analysis is that an investigator could more accurately predict habitat components of areas used for specific functions by a species.

Measuring habitat plots can be accomplished in many different ways. Considerations include plot shape and size, and the techniques used to measure them. James and Shugart [1970; see also James (1971)] presented a methodology commonly used in eastern deciduous forests; this was refined by Noon (1981). Whether or not the James and Shugart method is appropriate for western oak woodlands is unknown. Plot size can vary with the habitat and the activity range of the species studied. The objective of plot size is to include a representative sample of the variation found within the habitat of a species. James and Shugart's (1971) plots were 0.04 ha in size, whereas Gutierrez (1980) found that 0.02 ha plots were sufficient for describing mountain quail habitat in the sclerophyllous oak woodlands of the central California Coast Range. Morrison and Meslow (1983) used 0.01-ha plots to describe the habitats of brush-inhabiting birds in clearcut Douglas-fir habitats of the Oregon Coast Range.

Plot size will likely vary with the species studied and with the type of vegetation present. Pilot studies should be done to determine appropriate plot sizes for different birds and vegetation types.

The choice of habitat characteristics to be measured and the techniques used to measure them are integral to describing the habitat of a species. An investigator must have some prior knowledge of the biology and habitat-use patterns of the bird. James (1971) used the term "niche gestalt" to refer to how an organism perceived the environment, but a more appropriate explanation of this concept is that the "niche gestalt" is how an investigator perceives the species' environment. The closer the investigator's gestalt is in accord with how the organism perceives the environment, the more accurate the description of the habitat. Unfortunately, data on the biology and "niche gestalt" of many species are lacking; thus the investigator must rely on her or his field expertise to determine which components of the environment should be studied. Various techniques are used to quantify these habitat characteristics. These techniques range from ocular estimates to rather meticulous and often labor-intensive measurements. Each technique contains certain inherent biases and different techniques vary with regards to accuracy. Block and others (in press) compared habitat measurements with ocular estimates of the same characteristics and found that measurements provided more accurate estimates with greater precision than ocular estimates. Moreover, measurements tended to vary less among observers than did estimates. Consequently, actual measurements would be expected to yield a more accurate estimate of a species' niche gestalt than values obtained by estimation (i.e., "guessing").

Study of Bird Activity Patterns

To understand the modes of resource use by birds in greater detail, it is useful to measure activities of birds (Holmes 1981). Quantifying foraging activity has been the object of many studies. From a theoretical standpoint, this seems appropriate because food availability is generally acknowledged as a key factor in whether a bird survives and/or reproduces. In a more practical sense, foraging involves a large proportion of a bird's activity time, thus making it easier for an observer to obtain adequate numbers of samples. This does not negate the importance of other aspects of bird activity, since most bird activity is likely adaptive and certainly merits study. Studies should be flexible and designed to collect data measuring all aspects of bird behavior. Unfortunately, the costs of a study to determine all aspects of bird activity probably exceed the budgets of most projects, because adequate samples for many bird activities are precluded by the infrequency or secrecy of the activity.

Birds forage throughout the year, although the prey and methods used to capture prey vary across both time and space. Spatial and temporal variations might be attributed to differences in the phenologies of vegetation and of the prey available to birds. Consequently, studies should sample behavior across a range of conditions and times. The types of information that should be collected include general characteristics of the plant or object where foraging occurred, details of the perch and foraging substrates, and the foraging maneuver. These types of data provide detailed information about modes of resource use by species. Further, the patterns of microhabitat use by birds can be used by resource managers to determine how even fine-scale habitat alterations will affect selected species.

We observed activity locations and foraging behaviors of birds at the Tejon Ranch from 15 May to 20 June 1986. A bird was observed from 10-30 sec while foraging. We recorded the characteristics of the tree (when applicable) where the bird foraged (species, height, diameter, and vigor of the tree), characteristics of the foraging and perch substrates, and the foraging maneuver. Simple analyses of these data suggested that some birds used certain tree species with greater frequency than others (table 2). For example, northern orioles were observed using valley oak with greater frequency than other oak species, whereas Nuttall's woodpeckers, plain titmice, and white-breasted nuthatches used blue oak with greater frequency (table 2). In contrast, black-headed grosbeaks rarely were observed foraging on oaks and appeared to use California buckeye (*Aesculus californicus*) more frequently than any other foraging substrate (table 2).

The use of oaks and other hardwoods by birds is not restricted to oak woodlands. We used the same general methods as those used at the Tejon Ranch to study activity patterns of birds found in the mixed-conifer habitats of Blodgett Forest. All species studied used California black oaks for part of their foraging activities, with the Nashville warbler making heavy use of oak (table 3). The red-breasted sapsucker, pileated woodpecker, solitary vireo, warbling vireo, and black-headed grosbeak used hardwood species for at least 20 percent of their foraging activities; the Nashville warbler did so for almost 50 percent of its activities. Thus, alteration of the hardwood resource in the mixed-conifer zone may affect adversely some or all of these species.

Intensive observations of bird activities are therefore critical to understanding actual modes of habitat use by species. These data allow managers to more specifically assess tree species and substrate preferences by the birds. For example, a species might use a plant species in

Table 2. Relative frequency (percent) of use of foraging substrates by birds within oak woodlands at the Tejon Ranch, Kern County, California during the 1986 breeding season.

Species	n	Blue oak	Valley oak	California Black oak	Canyon live oak	Interior live oak	California buckeye	Other plants	Ground	Air
Nuttall's woodpecker	39	61.9	17.9	5.3	5.3	5.3	5.3			
Acorn woodpecker	22	18.2	31.8	18.2	4.5		4.5			22.7
White-breasted nuthatch	57	56.1	26.3	8.8	7.0	3.5		1.8	1.8	
Plain titmouse	81	57.3	9.7	4.9	2.4	9.8	7.3	3.7	4.9	
House Wren	22	13.6	31.8	4.5				13.6	37.5	
Ash-throated flycatcher	23	21.7	21.7			4.3		4.3	17.4	30.4
Black-headed grosbeak	29		13.7		6.9	10.3	31.0	17.2	13.7	6.9
Northern oriole	46	11.4	50.0	13.6	4.5	6.8	11.4		11.4	

Table 3. Tree species used (pct) by foraging birds at Blodgett Forest Research Station, El Dorado County, California during spring-summer 1983-85[1].

Species	N[2]	Black oak	Tan oak	Other Hardwood[3]	Coniferous[4]
Red-breasted sapsucker (Sphyrapicus ruber)	91	15	1	7	76
Hairy woodpecker	89	14	0	3	81
Pileated woodpecker (Dryocopus pileatus)	48	23	0	1	76
Dusky flycatcher	45	16	4	5	72
Mountain chickadee (Parus gambeli)	62	8	3	2	87
Chestnut-backed chickadee (P. rufescens)	129	13	0	1	84
Brown creeper	124	10	2	-	86
Red-breasted nuthatch (Sitta canadensis)	126	14	0	1	84
Solitary vireo (Vireo solitarius)	79	23	0	1	77
Warbling vireo	50	26	0	6	68
Nashville warbler (Vermivora ruficapilla)	98	38	1	8	48
Yellow-rumped warbler	84	11	1	2	84
Black-headed grosbeak	86	19	0	7	71

[1]Percentages do not total 100 percent because not all foraging substrates are given.

[2]Number of individuals observed; sexes combined.

[3]Primarily madrone, chiquapin (sic), and white alder (Alnus rhombifolia).

[4]Douglas-fir, white fir, incense cedar, and ponderosa and sugar pine.

much greater frequency than it occurs in the macrohabitat. Detailed observations may indicate, however, that the bird concentrates foraging activities on stems of a certain size or exhibiting a certain vigor (e.g., live, dying, dead). These types of data are critical for the formulation of species-specific management plans, as they indicate the species and relative vigor of trees and substrates used by birds.

CONCLUSIONS

The study of birds within any habitat requires first a conceptual understanding of the processes that influenced their distributions, and second, intensive field research to determine viability and patterns of resource use of the species. Much research is restricted to a single season or within a particular site. Although this approach provides useful information, the results of such study may be valid only for the place and time the data were collected. More extensive data are required to determine year-round patterns of habitat and resource use by birds. There are no shortcuts for obtaining the information.

Determining population parameters, habitat quality, and resource-use patterns of species are both time- and labor-intensive. These data are essential for the development of species-specific models to assess habitat quality and to predict the effects of various land-use practices on the viability of oak woodland birds. These models must be based on empirical field data that include characteristics of the habitat thought to be critical to the survival of the species. Once developed, these models must be scrutinized to determine their temporal and spatial applications through rigorous testing and refinement. Only through such integrated study of avian-habitat-resource relationships will researchers begin to understand the processes that underlie bird distributions and abundances, and to provide managers a basis from which positive management approaches can be advanced.

Acknowledgments: We thank Donald Geivet and Russell Mohr for providing access and logistical assistance at the Tejon Ranch. Robert Heald and the staff of Blodgett Forest helped facilitate study there. Reviews by Martin G. Raphael, William Laudenslayer, and Jared Verner improved this paper. Special thanks to Lorraine Merkle for technical assistance.

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Wildlife Habitats of California's Hardwood Forests-Linking Extensiye Inventory Data With Habitat Models[1]

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Abstract: An approach for inventorying and assessing California's wildlife habitats is presented. It links data from an extensive, sample-based inventory with models developed by the California Wildlife Habitat Relationships Program to assess current and future habitat capability. Over 300 wildlife species find hardwood habitats optimum or suitable for reproduction. The approach to habitat evaluations is demonstrated for two of these species. In California, hardwood-dominated habitats occupy 7,170,000 acres (2,868,000 ha) of forest lands outside National Forests, parks, and wildernesses. Most of the area (89 percent) is privately owned. Eighty three percent of the hardwood area occurs on woodlands; 17 percent is on timberland. Most of the area of hardwood habitats (81 percent) consists of stands in the pole/small tree size class. The area is almost equally divided between stands of sparse and dense canopy closure.

BACKGROUND AND INFORMATION NEEDS

Interest in California's hardwoods has grown markedly over the past few years, witnessed by the recent increase in oak-related research (Muick and Bartolome 1985), the formation of a Hardwood Task Force by the California Board of Forestry, and the holding of symposia such as this. The importance of hardwoods to wildlife is one of the major hardwood-related issues that has emerged.

California's tremendous ecological diversity offers many opportunites (sic) for wildlife; about 600 terrestrial vertebrates are native to the State (Laudenslayer and Grenfell 1983). The data base of current knowledge about these species, compiled by the California Wildlife Habitat Relationships Program (WHR),[3] indicates that more than half of the wildlife species find hardwood-dominated habitats optimum or suitable for reproduction--more than any other broad vegetation type. Of the six broad vegetation types, hardwoods rank third in numbers of wildlife species that depend solely on that type for habitat for reproduction (table 1).

In the last two decades, concerns for wildlife have been addressed to a greater degree in allocating natural resources, developing land use plans, and formulating forest regulations. Nevertheless, forest planners and policymakers have been limited in their ability to account for wildlife in their decisions by the lack of basic information about the resource, and by the lack of analytical tools. To date, no statewide inventory or assessment of California's wildlife habitats has been conducted. State- and regional-level planning for wildlife requires current data on the extent and characteristics of vegetation--primary determinants of habitat conditions on forest land. Models for translating these data into information on wildlife habitat and populations are also needed.

These ingredients of a habitat assessment have recently become available. However, producing a statewide assessment is an enormous and complex task presenting unique challenges. Information must be provided for a great diversity of vegetation types and wildlife species, in a format that is useful for meeting a variety of planning and management objectives. The various State and Federal agencies entrusted with managing California's wildlife are concerned with maintaining species diversity and exploitable populations of commercial and game species. In this paper we introduce a strategy for broad-scale assessment of California's wildlife habitats. Using the State's hardwood habitats as a case study, we demonstrate how State- or regional-level information for wildlife planning can be developed. Our approach is based on the assumption that qualitative habitat assessments, based on level-one models of wildlife-habitat relationships (Nelson and Salwasser 1982, Mayer 1983), are acceptable for broad-scale planning. Level-one models provide data for wildlife species that indicate relative suitability of a habitat for reproduction, foraging, and cover. Models of this level of resolution cannot be used to predict actual animal abundance. In demonstrating our approach, we also provide useful information for addressing some of the current issues related to California's hardwood habitats.

[1]Presented at the Symposium on Multiple-Use Management of California's Hardwood Resources, November 12-14, 1986, San Luis Obispo, California.

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[3]California wildlife-habitat relationships data base--1986, on file with the California Department of Fish and Game, Sacramento, California.

Table 1--Number of wildlife species using broad vegetation types for reproduction

Broad vegetation type and wildlife species group	Type provides optimum or suitable habitat	This is only source of optimum or suitable habitat
	Number of species	
Hardwood-dominated		
Herpetofauna	58	1
Birds	168	12
Mammals	105	7
All species	331	20
Conifer-dominated		
Herpetofauna	55	1
Birds	148	13
Mammals	108	4
All species	311	18
Shrub-dominated		
Herpetofauna	62	0
Birds	85	5
Mammals	102	6
All species	249	11
Desert types		
Herpetofauna	58	8
Birds	98	15
Mammals	74	8
All species	230	31
Wetland types		
Herpetofauna	27	6
Birds	89	30
Mammals	53	1
All species	169	37
Grassland types		
Herpetofauna	32	0
Birds	56	5
Mammals	77	5
All species	165	10

AN APPROACH FOR ASSESSING CALIFORNIA'S WILDLIFE HABITATS

The Approach

The challenge of assessing California's forest and rangeland resources has recently brought together departments of two resource agencies: the Forest and Rangeland Resources Assessment Program (FRRAP) of the California Department of Forestry, and the Forest Inventory and Analysis Research Unit (FIA) of the USDA Forest Service, Pacific Northwest Research Station. These two groups have cooperated for more than 6 years to complete a statewide assessment of the State's forest and rangeland resources. An evaluation of the effects of land management and ownership change on wildlife is part of this assessment.

We met this challenge by developing an approach for assessing wildlife habitat that links data from FIA's statewide, sample-based inventory of forest lands with models developed as part of the California WHR Program. We first classify each FIA field plot according to the type of vegetation (i.e. wildlife habitat) present. Plot data are then expanded using FIA's double sample design to estimate area by wildlife habitat in various regions of the State (fig. 1). Finally, using models of wildlife-habitat relationships available in the WHR data base, we translate the area estimates into information on current availability of suitable habitat for selected wildlife species. By projecting future forest conditions, we can also evaluate future habitat capability under alternative scenarios of land ownership, use, and management.

The California Wildlife Habitat Relationships Program--a Source of Analytical Models

The WHR Program in California was initiated by the USDA Forest Service and the California Department of Fish and Game, in cooperation with the California Interagency Wildlife Task Group. A primary goal of the Program is to provide users a credible and more efficient mechanism for evaluating the consequences of land management

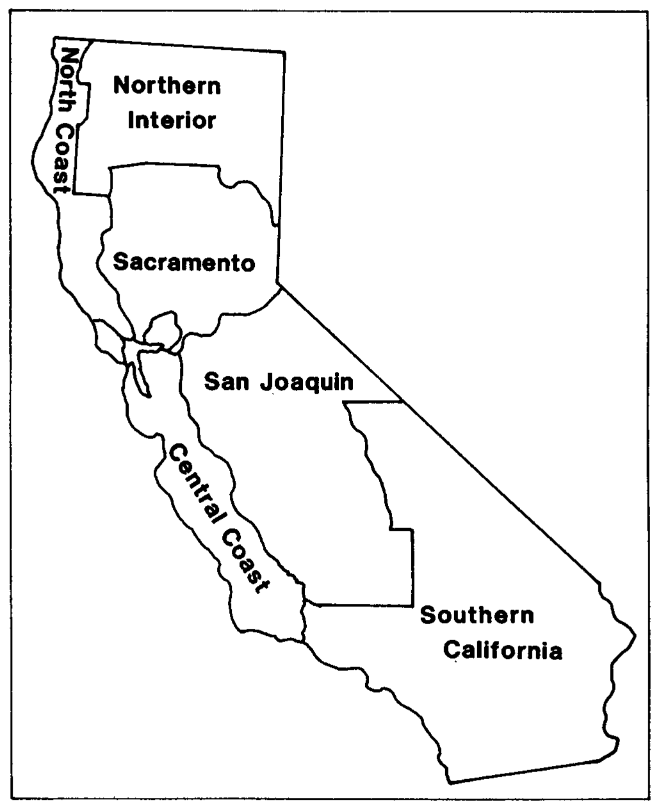

Figure 1--Resource areas in California

alternatives on wildlife. Another Program goal is to improve standardization and uniformity in habitat inventory, classification, and evaluation through increased communication and coordination among agencies and individuals (Grenfell and others 1982).

The core of the WHR Program is a systematically organized, computer-accessible data base of current knowledge about the life history characteristics of more than 600 terrestrial vertebrates, and about the relative capability of different environments to support them. Two features of the data base make it well suited to using data from an

a wide geographic area and a broad array of wildlife species, and it uses a single, uniform habitat classification system.

<u>The FIA Inventory--a Source of Habitat Data</u>

The concept of using data gathered from a sample-based inventory to assess habitat conditions over extensive areas is relatively new. The FIA inventory, in fact, offers several advantages as a framework for such an effort: (1) an established grid of permanent plots across all lands except National Forests, parks, and wildernesses; (2) an existing land classification system in use across the United States; (3) a design that provides confidence intervals for estimated variables; (4) periodic measurement data; and (5) multiresource data from the same sample plots, providing capability for assessing resource interactions. While early inventory efforts by FIA concentrated on timber resources, several changes to the inventory design were made for the recent survey of California. For the first time, tree and stand measurements were taken in the State's extensive oak woodlands (Bolsinger in press; McKay 1987). In addition, new procedures were incorporated for collecting the kinds of information important for evaluating wildlife habitat (Ohmann 1983).

The FIA sample design and data are discussed in detail in another paper in these proceedings (McKay 1987). Briefly, the sample design approximates Cochran's (1977) double sampling for stratification. The primary sample consists of a systematic grid of about 80,000 randomized photo points, with an average interval of 0.85 miles (1.37 km). During photo interpretation, each point was classified by broad ownership class, land class (timberland, other forest, or nonforest[4]), and other attributes.

The secondary sample consists of every 16th photo point, with a grid interval of 3.4 miles (5.4 km). At each grid point in timberland, field crews established or remeasured a permanent inventory plot consisting of five sample points distributed over about 5 acres (2 ha), and recorded detailed site and vegetation data. In other forest, which includes the hardwood woodlands, ground plots were established at every other grid point (about 6.8 miles (10.8 km) apart). Each timberland plot represents an average of 7,400 acres (2,960 ha); plots in other forest represent about 29,600 acres (11,840 ha). About 1,000 timberland and 400 other forest plots were established and measured from 1981 to 1984.

AN INVENTORY OF CURRENT HABITAT CONDITIONS

<u>Vegetation Types</u>

There are over 30 species of hardwoods in California, which have varying relationships with wildlife. Hardwoods are found growing in pure stands or mixed with conifers on productive timberland, in woodlands, as scattered trees in the vast foothill savannas, and in riparian strips at all elevations. Many systems for classifying this diverse vegetation have been developed. In this analysis we consider only those lands meeting the FIA definition of forest land. In describing the vegetation of these areas, we use the habitat classification system of the California WHR Program[5]. The WHR habitats are identified by the composition ("vegetation type") and structure (size and canopy closure class, or "stage") of vegetation currently dominating the site. Of the 25 tree vegetation types recognized by WHR, we focus on the eight hardwood habitats sampled by FIA field plots in this analysis. Descriptive information about the composition and structure of vegetation in these habitats is contained in the WHR habitat guide (Mayer and Laudenslayer in press).

In classifying FIA field plots, vegetation type was usually determined by translating the field-recorded CALVEG[6] series into the

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[4]Forest land is land that is capable of 10 percent stocking of trees and is not developed for nonforest use. Timberland is forest land capable of producing 20 cubic feet or more per acre per year of industrial wood. Other forest is forest land that cannot produce successive crops of trees suitable for industrial roundwood.

[5]Salwasser, Hal; Laudenslayer, William F., Jr. California Wildlife and Fish Habitat Relationships (WFHR) System: products and standards for wildlife. Unpublished document on file with the U.S. Department of Agriculture, Forest Service, Pacific Southwest Region, San Francisco, California; California; 1982. 25 p. and appendices.

[6]Parker, Ike; Matyas, Wendy. CALVEG--a classification of California vegetation. Unpublished document on file with the U.S. Department of Agriculture, Forest Service, Pacific Southwest Region, San Francisco, California; 1979. 159 p.

Table 2--Area of unreserved forest land outside National Forests by broad vegetation type, land class. and ownership class. California. January 1, 1985[1]

Broad vegetation type	Timberland			Other Forest			Total
	Privately owned	Publicly owned	All ownerships	Privately owned	Publicly owned	All ownerships	
	Thousand acres						
Tree types:							
Hardwoods	1,086	132	1,218	5,265	688	5,952	7,170
Conifers	6,170	374	6,544	655	844	1,498	8,042
All trees	7,255	506	7,762	5,920	1,531	7,451	15,212
Shrub types	190	10	200	3,321	1,215	4,535	4,736
Herbaceous types	18	--	18	--	--	--	18
Unclassified	--	--	--	55	31	86	86
Total	7,464	516	7,980	9,295	2,777	12,072	20,052

[1]Totals may be inexact due to rounding.

Table 3--Area of unreserved forest land outside National Forests by hardwood vegetation type, resource area, and land class, California, January 1, 1985[1]

Resource area and land class	Hardwood vegetation type								
	Coastal oak woodland	Valley oak woodland	Blue oak oak woodland	Blue oak-Digger	Montane hardwood	Montane hardwood-conifer	Valley-foothill riparian	Eucalyptus	All hardwood vegetation types
	Thousand acres								
North coast:									
Timberland	14	8	8	--	593	147	7	--	778
Other forest	126	84	--	--	293	--	--	--	503
Total	140	92	8	--	886	147	7	--	1,281
Northern interior:									
Timberland	--	--	--	--	79	49	--	--	127
Other forest	--	--	109	137	192	124	--	--	562
Total	--	--	109	137	270	173	--	--	689
Sacramento:									
Timberland	--	--	--	8	113	48	--	--	170
Other forest	--	--	525	730	205	--	3	--	1,492
Total	--	--	525	738	318	48	33	--	1,662
Central coast:									
Timberland	25	--	--	--	33	8	--	--	66
Other forest	673	-90	135	359	45	--	--	45	1,346
Total	698	90	135	359	78	8	--	45	1,412
San Joaquin and southern Calif.:									
Timberland	--	--	--	7	55	15	--	--	77
Other forest	105	--	782	918	189	19	--	36	2,049
Total	105	--	782	925	244	34	--	36	2,126
All resource	943	182	1,559	2,159	1,796	410	40	80	7,170

[1]Totals may be inexact due to rounding.

corresponding WHR vegetation type. CALVEG series consist of general dominance types that are based on existing overstory vegetation. Tables 2-4 present information on current area of the WHR vegetation types. The tables include only those forest lands that are outside National Forests, parks (including national, State, county, and municipal), and wilderness areas.

Table 4--Area of unreserved forest land outside National Forests by hardwood vegetation type and ownership class, California, January 1, 1985[1]

Hardwood Vegetation type	Ownership class Private	Public	All
	Thousand acres		
Coastal oak woodland	863	80	943
Valley oak woodland	140	42	182
Blue oak woodland	1,392	168	1,559
Blue oak-Digger pine	1,891	268	2,159
Montane hardwood	1,595	201	1,796
Montane hardwood-conifer	350	60	410
Valley-foothill riparian	40	--	40
Eucalyptus	80	--	80
All hardwood types	6,351	820	7,170

[1]Totals may be inexact due to rounding.

Size and Canopy Closure Classes

The vegetation structure of the WHR habitats is defined by size class and canopy closure class. Size classes of tree vegetation types are defined by the size of the dominant vegetation present. For FIA field plots in hardwood types, we classified size class based on the quadratic mean diameter of hardwood trees in the stand. Because of the broad-scale, planning-level nature of our habitat assessment, we grouped the WHR size classes into three categories: seedling/sapling (0-6.0 inches d.b.h.), pole/small tree (6.1-24.0 inches d.b.h.), and medium/large tree (>24.0 inches d.b.h.).

The WHR habitat classification system recognizes four broad canopy closure classes for tree vegetation types, which we grouped into two for our analysis: sparse (0-39 percent canopy closure) and dense (40-100 percent canopy closure). To classify canopy closure classes of FIA field plots, we used information on the height and canopy closure of vegetation recorded on a 16-foot (5-m) fixed-radius, 0.02-acre (0.01-ha) plot centered on each of the five sample points. Tables 5 and 6 present information on current size and canopy closure classes of the hardwood vegetation types.

Table 5--Area of unreserved forest land outside National Forests by hardwood vegetation type, size and canopy closure classes, California, January 1, 1985[1]

Size and canopy closure classes	Hardwood vegetation type: Coastal oak woodland	Valley oak woodland	Blue oak oak woodland	Blue oak-Digger pine	Montane hardwood-	Montane hardwood-conifer	Valley-foothill riparian	Eucalyptus	All hardwood vegetation types
	Thousand acres								
0 6 inches d.b.h.:									
0-39 pct cover	36	--	202	360	154	118	--	--	869
40-100 pet cover	--	--	27	101	127	100	--	--	355
Total	36	--	229	461	281	218	--	--	1,225
6.1-24 inches d.b.h.:									
0-39 Dot cover	381	129	945	1,083	286	99	40	36	2,997
40-100 pet cover	527	53	353	555	1,223	74	--	45	2,830
Total	908	182	1,298	1,638	1,509	173	40	80	5,827
>24 inches d.b.h.:									
0-39 pot cover	--	--	33	60	--	19	--	--	112
40-100 pot cover	--	--	--	--	6	--	--	--	6
Total	--	--	33	60	6	19	--	--	118
All classes:									
0-39 pot cover	417	129	1,180	1,503	440	236	40	36	3,978
40-100 pet cover	527	53	380	656	1,356	174	--	45	3,191
Total	943	182	1,559	2,159	1,796	410	40	80	7,170

[1]Totals may be inexact due to rounding.

Table 6--Area of hardwood vegetation types on unreserved forest land outside National Forests by ownership, land and size classes, California, January 1, 1986[1]

Land class and size class (inches d.b.h.)	Ownership class			
	Public	Forest industry	Other Private	All owners
	Thousand acres			
Timberland:				
0-6.0	11	78	164	253
6.1-24.0	116	153	691	959
>24.0	6	--	--	6
Total	132	231	855	1,218
Other forest:				
0-6.0	140	--	832	972
6.1-24.0	547	75	4,246	4,868
>24.0	--	--	112	112
Total	688	75	5,190	5,952
All classes	820	306	6,045	7,170

[1]Totals may be inexact due to rounding.

EVALUATING HABITAT CAPABILITY

WHR's level-one models of wildlife-habitat relationships represent a major advancement in analytical tools for predicting the effects of habitat alterations on wildlife. For each wildlife species, the models provide data that indicate the relative suitability (optimum, suitable, or marginal) of each habitat for reproduction, foraging, and cover. The models do not provide data for predicting animal abundance. They do, however, allow the analyst to evaluate wildlife habitat qualitatively--an acceptable level of analysis for many broad-scale, planning-level applications.

In applying the models, the analyst must compare the amounts of suitable habitat before and after a management action. Changes in habitat area can be actual changes detected by inventorying or monitoring, or potential changes as portrayed through habitat projection or simulation. If a particular habitat is essential to a species' survival, then an increase or decrease in the area of that habitat has a corresponding effect on the species' ability to survive. For example, if a wildlife species is restricted to one or two size or canopy closure classes for reproduction, and the area of these stages is reduced by 50 percent over a given period of time, one would expect a decline in animal abundance.

For our examples of how habitat capability can be evaluated using FIA data and the level-one models, we chose two wildlife species found in California's valley-foothill hardwoods[7]. The gray fox (Urocyon cinereoargenteus) prefers early-successional stages as habitat, and the plain titmouse (Parus inornatus) uses later stages. For this analysis, we translated the qualitative ratings of habitat suitability into numerical ratings of probability of occurrence (presence or absence). For each life requisite (breeding, feeding, and resting), vegetation types and stages not used by the wildlife species received a rating of zero. Marginal habitats received a rating of 0.3, suitable 0.6, and optimum 1.0. For each habitat stage, the ratings for the three life requisites were then averaged to derive the composite ratings, or habitat suitability index (HSI), shown in figure 2.

Available habitat units can be calculated for a given point in time by multiplying the area in each stage (fig. 3) by the corresponding rating (fig. 2), and then summing across all stages in the vegetation types. Future habitat units are calculated based on a projected inventory of available vegetation types and stages. In our hypothetical example, we show how habitat availability would be affected if the total area of valley-foothill hardwoods in the Sacramento and San Joaquin resource areas were to decrease by about 175,000 acres (70,000 ha) over the next decade (figs. 4 and 5). The proportion of the remaining area that is comprised of late-successional stands would also decrease. Under these conditions, the plain titmouse would have greater difficulty finding adequate habitat; available habitat units would decrease by about 8 percent. Suitable habitat for the gray fox would decrease to a lesser degree (by about 4 percent) (fig. 6)

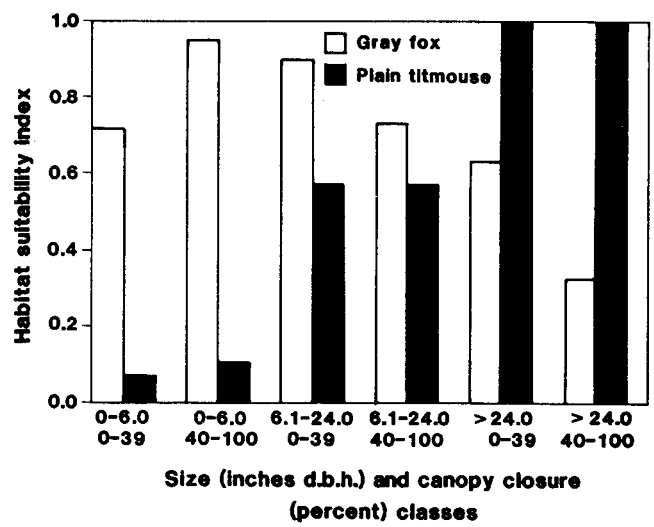

Figure 2--Habitat suitability indices for the valley-foothill hardwoods, California

[7]Valley-foothill hardwoods include blue oak woodland, blue oak-Digger pine, valley oak woodland, and coastal oak woodland.

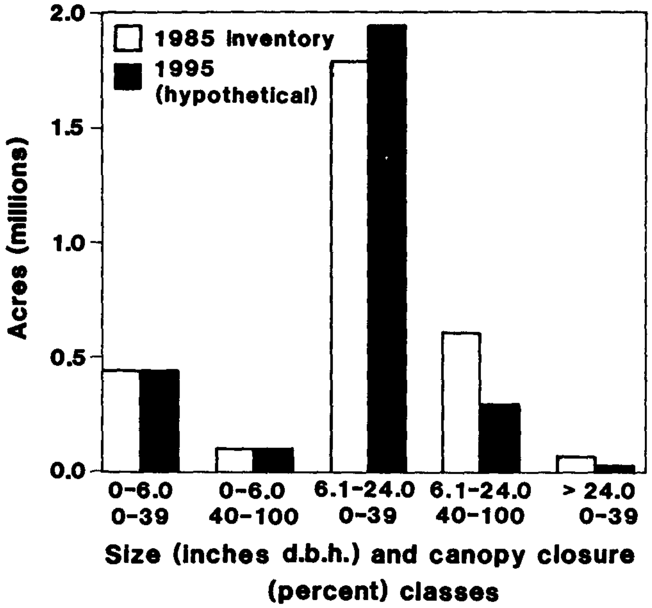

Figure 3--Area of valley-foothill hardwoods in the Sacramento and San Joaquin resource areas, California

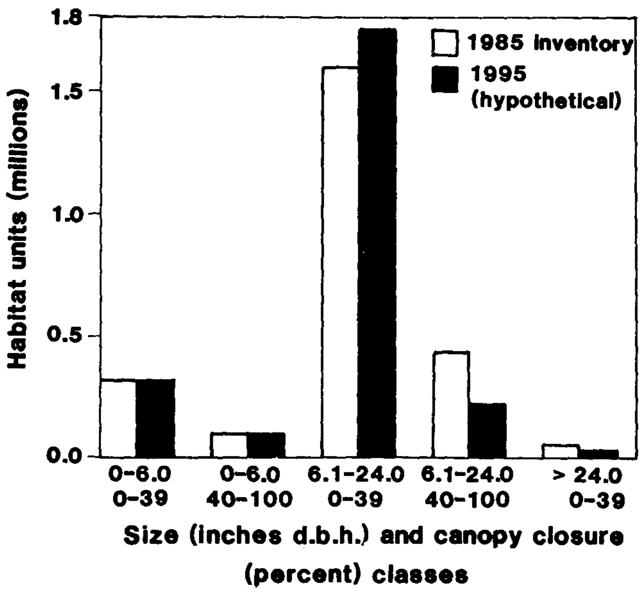

Figure 4--Available habitat units for the gray fox in valley-foothill hardwoods, Sacramento and San Joaquin resource areas, California

Given this kind of information, planners can compare projected habitat units achieved under alternative scenarios and select the one that most closely meets objectives. The magnitude of potential adverse situations can also be determined. Specific measures aimed at avoiding problems can be taken following further research into the nature of the problem, how it varies by locality, and available alternatives for mitigating negative impacts.

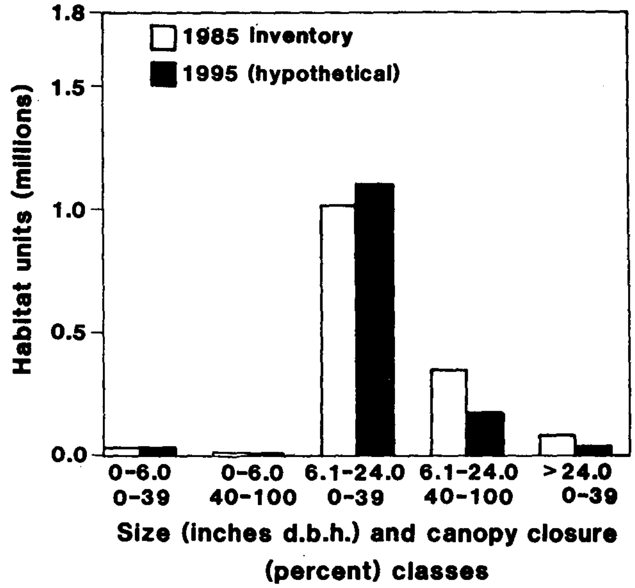

Figure 5--Available habitat units for the plain titmouse in valley-foothill hardwoods, Sacramento and San Joaquin resource areas, California

INTERPRETING AND APPLYING THE HABITAT INFORMATION

Several things must be considered when interpreting or applying the estimates of habitat area. First, the estimates are subject to sampling error (see discussion in McKay 1987). However, because the information is intended to be used at the planning level, a greater level of sampling error is acceptable than for making on-the-ground management decisions. The estimates of habitat area may also include nonsampling kinds of error, but these have been minimized through careful quality control and the standardization of field and analytical procedures. Furthermore, the WHR habitats define very general kinds of vegetation, overriding the need for highly precise input data.

Our estimates of habitat area may differ from other published estimates of area by forest or vegetation type, as a result of differing definitions and/or sampling procedures. In particular, estimates of area by hardwood forest types reported by Bolsinger (in press) may appear to conflict with our estimates of WHR vegetation types. However, direct comparisons of area estimates using the two classification systems are impossible, because the forest types and the WHR types do not correspond exactly. Furthermore, Bolsinger's forest types are assigned based on the tree species with the plurality of basal area, as determined from the tree tally. The WHR types are based on an assessment of overall conditions in the general 5-acre (2-ha) plot area.

Users of our habitat data should also remember that they indicate existing, not potential, vegetation. In addition, we classified plots using a "top-down" approach. Any stand with at least 10 percent canopy closure of trees is

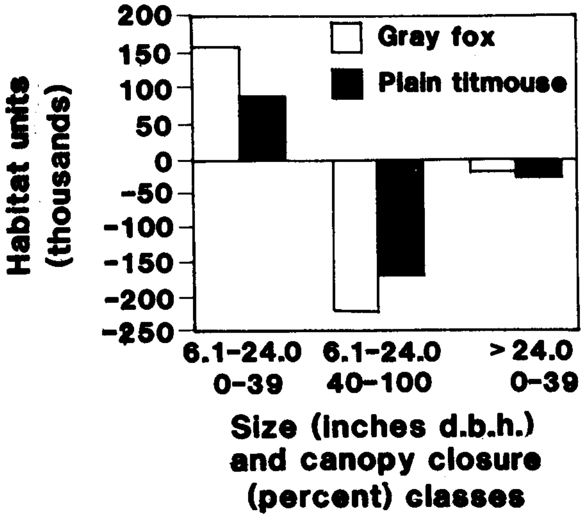

Figure 6--Change in available habitat units in valley-foothill hardwoods, Sacramento and San Joaquin resource areas, California

considered a tree habitat regardless of understory, which may vary greatly. Heavily disturbed timberland or woodland sites with less than 10 percent canopy closure of trees are considered shrub or nonforest habitats and are not included in the hardwood area. Furthermore, some conifer WHR types commonly support hardwood vegetation in their early successional stages. These stands are included in the tables presented here. For example, hundreds of thousands of acres in the North Coast that were formerly conifer-dominated forests now support tanoak (*Lithocarpus densiflorus* (Hook. & Arn.) Rehd.) and Pacific madrone (*Arbutus menziesii* Pursh). These stands are classified here as montane hardwood.

A drawback of using sample-based inventory data for assessing habitat relates to the lack of spatial information. Although we can describe individual stands in great detail, we lack information on surrounding forest conditions, and on the area covered by individual stands. The FIA inventory data could be augmented with such information in the future if the need arises. For the time being, this limitation can be minimized through careful selection of wildlife species for evaluation. The suitability of habitat for wildlife species that are highly dependent on "edge," or on a certain juxtaposition or interspersion of habitats and stages within their home range or territory, should not be evaluated using FIA plot data alone. Wildlife species that require stands of large area are also poor choices for habitat evaluation.

Finally, how closely our inventory of suitable habitat reflects the real world is directly related to how well the level-one WHR models reflect wildlife preference for habitats. As the models are validated, or more sophisticated ones developed, we can improve predictions of habitat suitability made with FIA inventory data.

A LOOK TO THE FUTURE

Clearly, providing information on habitat conditions on forest lands inventoried by FIA completes only one piece of the total resource picture. Future work should be undertaken to obtain compatible habitat data for all lands in the State, including National Forests, reserved areas, and nonforest lands.

Future evaluations of wildlife habitat using FIA data can be improved by applying additional information from the FIA inventory and other sources. The FIA data base contains a vast amount of data not accommodated by level-one WHR models. Many of the FIA data relate to habitat elements such as understory vegetation and snags. This kind of information, which can be used to supplement habitat evaluations based on level-one models, may be summarized in future publications. The FIA habitat data may also be used to produce maps. By plotting FIA sample locations on map overlays, we can display the habitat data in a form suitable for discerning general patterns across the landscape.

Future wildlife assessments by FRRAP will incorporate a "value ranking" (Ogle 1981) in the evaluation process. The ranking is used to adjust habitat units upward or downward according to the perceived value of the habitat to wildlife. Loss of a vegetation type or successional stage that is uncommon, or that is used by a large number of wildlife species, is perceived as more critical than loss of more common or less used habitats. In a regional analysis such as that described in this paper, changes affecting critical habitats may be obscured because inventory estimates consist of large acreages. Changes in habitat area may appear small when expressed as a proportion of the total, even though the actual number of acres affected may be substantial.

Producing a statewide inventory of current, and potential future, wildlife habitats represents a critical first step towards ensuring the long-term survival of California's wildlife. Once the magnitude of potential impacts on selected indicator species of wildlife have been identified using the approach described in this paper, research may be done to learn more about the nature and location of any problems. Given similar resource data from future FIA inventories, actual changes in the amount and suitability of wildlife habitat on private lands can be monitored. The effectiveness of mitigation efforts can also be evaluated in this way. Documented information on trends in the resource will prove essential to sound multiresource planning for wildlife in California's forests.

ACKNOWLEDGEMENTS

We thank William Laudenslayer, USDA Forest Service, and Ellen Yeoman, Pacific Gas & Electric, for their timely and helpful technical reviews of the manuscript. Irene Timossi, University of

California, Berkeley, developed the habitat suitability indices and provided computer support in accessing the WHR data base. Katharine McDuffie, USDA Forest Service, wrote computer programs for screening the FIA field plot data. Finally, we thank the many individuals in the FIA research unit involved in collecting data and compiling the findings of the California inventory.

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Wildlife-Tanoak Associations in Douglas-fir Forests of Northwestern California[1]

Martin G. Raphael[2]

Abstract: I sampled characteristics of vegetation and estimated abundances of 61 vertebrate species on 166 sites representing early clearcut through mature seral stages of Douglas-fir forests in northwestern California. Tanoak was present in most stands and increased in canopy volume as stand age increased. The abundances of 12 bird species, 7 mammal species, and 5 salamander species were greatest in stands with greater tanoak canopy volume, suggesting that tanoak may be an important habitat component for these species. Capture rates of small mammals on clearcuts with and without tanoak, and among forested sites with varying tanoak volume, showed that some species, especially northern flying squirrel, Allen's chipmunk, and dusky-footed woodrat were very closely tied to tanoak, which provided mast and nesting cover. Management practices that eliminate tanoak are probably detrimental to these and possibly other species of wildlife in Douglas-fir forests.

Tanoak (Lithocarpus densiflorus) is the most abundant hardwood tree species in Douglas-fir (Pseudotsuga menziesii) forests of northwestern California. It often dominates the subcanopy layer at heights <35 m. Following fire or logging, tanoak regenerates by sprouting and can form a nearly solid canopy depending on previous stand conditions and on available soil moisture (Thornburgh 1982, Raphael in press, a). Because such dense regrowth can suppress regeneration of conifers for many years, tanoak has been considered a pest species and is the target of intensive suppression efforts (King and Radosevich 1980).

Tanoak contributes about 30 percent of the total cubic-foot volume of all hardwoods in California (Bolsinger 1980). Commercial use of tanoak has been low, but is increasing in northwestern California primarily to meet demands for pulpwood and fuelwood (Stine 1980). Because (1) the harvest rate of tanoak is likely to increase, and (2) removal of tanoak regeneration to reduce competition with conifers will continue, tanoak volume may decline in managed stands of the northwest. If so, how will this affect wildlife? To begin answering this question, I sampled wildlife populations and vegetation cover on a large number of sites and compared the abundances of wildlife species to the amount of tanoak at each site.

[1]Presented at the Symposium on Multiple-Use Management of California's Hardwood Resources, November 12-14, 1986, San Luis Obispo, California.

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METHODS

Study Area

Study sites were located on the Six Rivers, Trinity, and Klamath National Forests of northwestern California. Forest cover is dominated by Douglas-fir in association with an understory of tanoak, Pacific madrone (Arbutus menziesii), and a large variety of other tree and shrub species, depending on site conditions. Elevations of study sites varied from 427 to 1220 m, averaging 838 m.

Study Design

Extensive Survey

This study involved two complementary approaches. The first was an extensive 3-year survey of late-seral stands that varied from about 50 to >350 years old. For this survey, 136 sites were selected using Forest Service timber type maps, aerial photographs, and ground examinations. Each site was an area of about 10 ha, bounded by a circle with a 180-m radius and centered on a point that was marked on the ground. Terrestrial vertebrates were sampled on each site using four primary methods described by Raphael (1984).

Variable-Radius Circular Plots--A team of four trained biologists counted birds and squirrels from the center of each site during 12 10-min periods each spring and winter, 1981-83. Distances were estimated to each animal, permitting calculation of estimated density using the computer program TRANSECT (Laake and others 1979, Raphael in press, b).

Pitfall Traps--Pitfall traps were used to capture small mammals, amphibians, and reptiles. Arrays consisted of 10 2-gallon plastic buckets arranged in a 2x5 grid with 20-m spacing, buried flush with the ground surface and covered with plywood lids. One such array was placed at the center of each site. Each bucket was checked at weekly to monthly intervals from December 1981 through October 1983. For this study, I calculated the total captures of each species over the entire sampling period and the total number of trapnights for each site; capture rate was then expressed as the number of captures/1000 trapnights.

Drift Fence Arrays--Primarily to capture snakes, the sampling team installed a drift fence array on a randomly selected subset of 30 sites. An array consisted of two 5-gallon buckets placed 7.6 m apart and connected by an aluminum fence 7.6 m long by 50 cm tall, with a 20x76-cm funnel trap placed on each side of the center of the fence. Each array was in place from May to October, 1983. Captures from these arrays, and associated trapnights, were pooled with results of the pitfall arrays.

Track Stations--The team recorded tracks of squirrels and carnivores on each site using a smoked aluminum plate baited with tuna pet food (Barrett 1983, Raphael and others 1986). Each station was monitored for 8 consecutive days in August, 1981-83. A species was recorded as present on a site if it was recorded any time during these 3 years.

Vegetation Sampling--Characteristics of vegetation structure and composition were estimated from three randomly located, 0.04-ha circular plots located within 60 m of the center of each of the 136 sites. A sampling team measured characteristics of each live tree and snag >2 m tall within each circular plot. Canopy volume was computed for each tree using a modified version of the program HTVOL (Mawson and others 1976); tree volumes were summed for each species on each site. Stand age was estimated from the diameter-distribution of all conifers (Raphael 1984). Slope and aspect were measured at each site and were used to calculate an index of total yearly solar radiation (Frank and Lee 1966).

Data Analysis--I computed Pearson correlation coefficients between estimated abundance of each vertebrate species (except those too rare for valid analysis) and canopy volume of tanoak for all 136 sites. Because the correlations can be confounded by other habitat gradients, especially stand age, elevation, and solar radiation, I used partial correlation analyses to examine the correlation of tanoak volume and abundance with the effects of the other three gradients removed. All statistical analyses were conducted using the SPSS program package.

Intensive Sampling

Surface Search--To better capture salamanders, the sampling team conducted time- and area-constrained searches (Bury and Raphael 1983, Welsh, these proceedings) on a randomly selected subset of 87 sites from the extensive sample, plus an additional 60 sites representing early seral stages. A two-person team searched under all movable objects and within all logs on three randomly located 0.04-ha subplots (fall 1981, 1982) or within a 1-ha area for four person-hours (spring 1983). Results were expressed as mean captures/site; analyses included only those sites sampled in this manner.

For each capture, the observer recorded the species of salamander and its location, including the substrate where it was found, substrate size (and species, if appropriate) and its location relative to water. In addition, the observer recorded the size and species of all substrates examined where salamanders were not found in 1982. The latter data allowed an estimate of substrate availability.

Livetrap Grids--To estimate abundance and habitat associations of small mammals in more detail than possible with the extensive survey, the observers established livetrap grids on a subset of 27 sites representing both early and late seral stages. Each grid consisted of 100 25-cm Sherman live traps arranged in a 10x10 grid with 20-m spacing. Traps were checked once daily for 5 days during July, 1982-83. Capture rates were expressed as total captures/500 trapnights after adjusting for closed or damaged traps.

Observers also recorded vegetation characteristics within a 25-m^2 quadrat surrounding each trap. Percent cover was estimated for (1) bare ground and rocks; (2) litter; (3) logs >8 cm diameter and 1 m long; (4) understory cover (plants <2 m tall) of Douglas-fir, tanoak, Pacific madrone, and other species; and (5) overstory cover (vegetation >2 m tall) of Douglas-fir, tanoak, Pacific madrone, oak species, and other species, and total cover.

I used discriminant analysis to test for habitat differences between trap sites where animals were captured versus where they were not. For each trapsite, I counted the number of individuals of each mammal species captured at that site. For each discriminant analysis, the capture sites were weighted by the number of individuals of the species being considered. For example, if 50 of 100 traps captured 75 different deer mice, the discriminant analysis would be based on 50 noncapture versus 75 capture sites. Those sites with two captures would be represented twice in the analysis. Up to four individuals of a species were captured at each site, but multiple captures greater than two were rare.

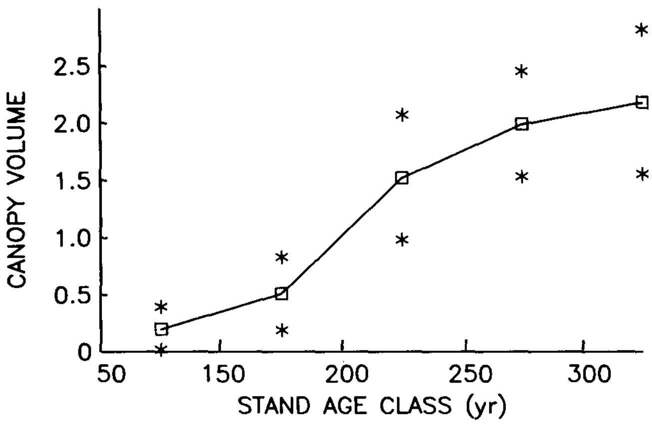

Figure 1--Canopy volume (m^3/m^2 of ground area) of tanoak in relation to stand age class in Douglas-fir forests of northwestern California. Asterisks indicate 95 percent confidence intervals.

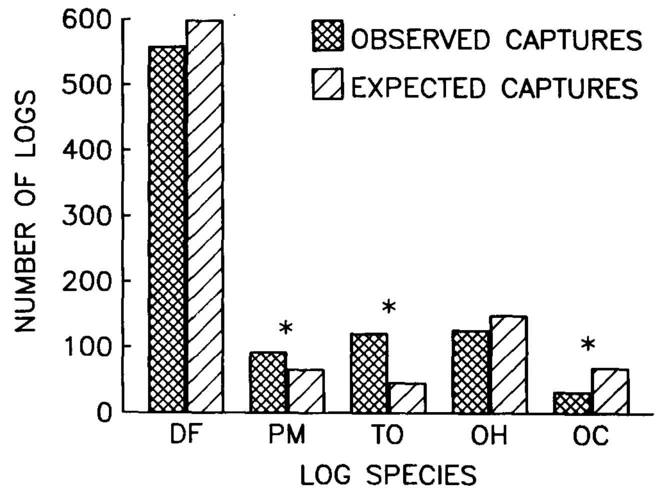

Figure 2--Frequency of salamander captures in logs of various species compared to expected captures based on numbers of logs searched. Log species codes are: DF, Douglas-fir, PM, Pacific madrone; TO, tanoak; OH, other hardwoods; OC, other conifers. Asterisks indicate significant differences between used and expected frequencies of use (binomial test, $P < 0.05$).

RESULTS

Tanoak Occurrence

Tanoak occurred on 115 of the 136 sites, and increased in canopy volume as stand age increased (ANOVA, test for linear trend, $P = 0.000$, fig. 1). Total canopy volume ranged from 0 to 5.4 m^3/m^2 ground surface and averaged 1.3 ± 0.1 $m/^3m^2$[sic] over all sites. Tanoak volume increased with increasing basal area of Douglas-fir ($r = 0.47$, $P = 0.001$) and higher elevation ($r = 0.20$, $P = 0.019$), and it decreased with higher solar radiation ($r = -0.37$, $P = 0.001$). Thus, canopy volume of tanoak was greatest in older, higher elevation stands on north-facing slopes.

Vertebrate Associations

Extensive Survey

The extensive survey yielded estimates of relative abundance for 61 species of amphibians, reptiles, mammals, and birds. The abundance of 24 of these species (5 salamanders, 7 mammals, and 12 birds) increased significantly ($P < 0.10$) as tanoak canopy volume increased (table 1). These correlations, although significant statistically, were rather weak (all $r < 0.50$), which was not surprising given the variability associated with this type of sampling. Separating the effects of solar radiation, stand age, and elevation reduced the number of species with significant correlations to 12 (3 salamanders, 3 mammals, and 6 birds; table 1).

Intensive Samples

Salamander Habitat Use--Observers recorded 1,631 salamander locations during three seasons of searches, and also recorded characteristics of 4,482 substrates where no salamanders were found. Most salamanders were found in association with logs (63 percent of locations); 13 percent of these were tanoak, whereas only 5 percent of searched logs were tanoak. Compared to available (searched) substrates, tanoak and Pacific madrone logs were used more often than expected from their availability (fig. 2); tanoak was the most highly preferred log substrate used by Del Norte salamander, ensatina, black salamander, and clouded salamander.

Small Mammal Captures--Observers recorded 1,029 captures of 513 individual small mammals in 1982 and 1,978 captures of 928 individuals in 1983 from 2,638 trap locations. Among the four most abundant species, capture rates were correlated with understory tanoak cover for all species except pinyon mouse (*Peromyscus truei*, table 2), which was apparently responding to cover of other shrubs (primarily *Quercus chrysolepis*).

Mean cover of shrubs (mostly tanoak), computed for each of six generalized seral stages, was greatest in the late clearcut (shrub/sapling) stage and lowest in the pole stage (fig. 3); relative abundance of the four common mammals followed a similar pattern (table 3).

I used discriminant analysis to evaluate whether mammals used particular microhabitats within plots. For each of the four most abundant mammals, I compared capture and noncapture trapsites using mean cover values for seven variables measured around each trap location. In each case, differences between capture and noncapture sites were statistically significant,

Table 1--Simple and partial correlations[1] of relative abundance of vertebrate species with canopy volume of tanoak among 136 late-seral sites in northwestern California.

Species	Simple Correlation	Partial correlation[2]
Salamanders		
Pacific giant salamander (Dicamptodon ensatus)	0.21*	0.10
Del Norte salamander (Plethodon elongatus)	0.47***	0.38**
Ensatina (Ensatina eschscholtzi)	0.45***	0.43***
Black salamander (Aneides flavipunctatus)	0.38**	0.27*
Clouded salamander (Aneides ferreus)	0.33**	0.16
Mammals		
Pacific shrew (Sorex pacificus)	0.17*	0.03
Allen's chipmunk (Tamias senex)	0.21*	0.03
Douglas' squirrel (Tamiasciurus douglasii)	0.15*	0.02
Northern flying squirrel (Glaucomys sabrinus)	0.28***	0.30***
Deer mouse (Peromyscus maniculatus)	0.18*	0.02
Black bear (Ursus americanus)	0.15*	0.16*
Fisher (Martes pennanti)	0.24**	0.23**
Birds		
Spotted owl (Strix occidentalis)	0.15*	0.00
Acorn woodpecker[3] (Melanerpes formicivorus)	0.16*	0.13
Red-breasted sapsucker (Sphyrapicus ruber)	0.17*	0.04
Olive-sided flycatcher (Contopus sordidulus)	0.23**	0.17*
Western flycatcher (Empidonax difficilis)	0.39***	0.32***
Hermit thrush (Catharus guttatus)	0.34***	0.13
Varied thrush[3] (Ixoreus naevius)	0.33***	0.35***
Hutton's vireo (Vireo huttoni)	0.19*	0.30***
Warbling vireo (Vireo gilvus)	0.38***	0.28***
Hermit warbler (Dendroica occidentalis)	0.15*	0.04
Wilson's warbler (Wilsonia pusilla)	0.23**	0.08
Purple finch (Carpodacus purpureus)	0.21*	0.25**

[1]Asterisks indicate level of significance: * = P<0.10, ** = P<0.01, *** =P<0.001, blanks = not significant
[2]Partial correlation after controlling for stand age, elevation, solar radiation.
[3]Winter populations.

Table 2--Correlation of capture rate (numbers of individuals per 500 trapnights) and mean cover of selected characteristics computed for 27 study sites. Only significant correlations (P < 0.05) are reported.

Characteristic	Species[1]			
	PEMA I	PETR I	NEFU	TASE
Litter	-0.48			-0.72
Logs				
Bare ground	0.57			0.61
Ground vegetation	0.40			0.42
Tanoak <2 m	0.53		0.52	0.69
Other <2 m		0.33		0.43
Total >2 m	-0.60			-0.69

[1]PEMA = deer mouse, PETR = pinyon mouse, NEFU = dusky-footed woodrat, TASE = Allen's chipmunk.

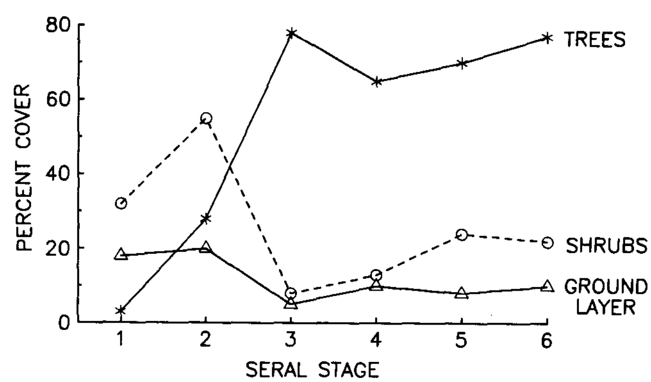

Figure 3--Percent ground cover of vegetation in three height strata among six seral stages of Douglas-fir forests. Values are averages from 300, 300, 500, 472, and 566 quadrats (25 m^2) in stages 1-6, respectively. See Table 3 for a description of seral stages.

Table 3--Average capture rates (animals/500 trapnights) of common mammals among seral stages of Douglas-fir forest in northwestern California.

Species	Seral stage[1]					
	1	2	3	4	5	6
Allen's chipmunk	8.7	27.3	0.3	1.0	3.8	3.4
Deer mouse	58.7	59.0	23.7	13.2	58.8	36.4
Pinyon mouse	2.7	15.0	4.7	12.6	4.6	1.6
Dusky-footed woodrat	1.7	3.0	0.3	0.8	5.4	3.8
Totals	71.8	104.3	29.0	27.6	72.6	45.2

[1]1 = early clearcut (N = 3), 2 = late clearcut (N = 3),3 = Pole (< 100 years, N = 3), 4 = sawtimber (100-150 years, N = 5), 5 = mature (150-250 years, N = 7), 6 = old growth (> 250 years, N = 6).

although the differences were weak (R^2 varied from 3 to 7 percent, table 4). Results generally paralleled those derived from the correlations reported earlier (table 2). Understory tanoak cover was the most consistently important variable. Except for pinyon mice, these animals had a tendency to enter traps surrounded by a higher than average amount of tanoak. Pinyon mice, in contrast, were most often captured in drier, rocky sites dominated by canyon live oak. In addition to having greater tanoak cover, Allen's chipmunk capture sites had much lower litter and higher log cover than noncapture sites (table 4). Although log cover varied little among the plots and was not correlated with chipmunk abundance among plots (table 2), the large F-ratio and high correlations with the discriminant function (table 4) indicated that log cover may be an important habitat characteristic for chipmunks.

DISCUSSION

This study provides strong circumstantial evidence that tanoak is an important habitat component for at least 16 of the 61 vertebrate species I sampled in Douglas-fir forests of northwestern California. For birds and larger mammals (nine species, table 1), evidence for this association was based strictly on the correlation between abundance of each species with canopy volume. Some of these correlations may be spurious because of confounding with other habitat characteristics (even though I controlled for other major habitat gradients) and because of the ever-present risk that even random data will yield statistically significant correlations some of the time. However, it is very unlikely that all of these correlations were spurious. For example, 24 of the 61 simple correlations were significant at the 10 percent level or better (table 1), whereas only three significant positive correlations would be expected by chance alone.

Further evidence that these correlations are not spurious is found in Verner's (1980) review of breeding bird associations with oaks (Quercus spp). For 8 of the 12 species of birds whose abundance was correlated with tanoak, Verner presented documented use of oaks for nesting and feeding. Considering only those six species with significant partial correlations between abundance and tanoak volume, only one (varied thrush) was not documented as using tanoak by Verner, but this species, which occurred only in winter in my study area, was not included in Verner's list because he considered only breeding birds.

Evidence based upon the intensive salamander searches and mammal livetraps is stronger because it shows either actual use of tanoak or at least consistent presence of tanoak in close proximity with the animal. These data reinforced correlational results for three species (ensatina, Del Norte salamander, and black salamander) and provided evidence for considering four additional species as tanoak associates (clouded salamander, deer mouse, Allen's chipmunk, and dusky-footed woodrat).

These wildlife species use tanoak in a variety of ways. Salamanders use tanoak logs for resting or hiding cover and perhaps nesting. Mammals feed on tanoak mast (e.g., black bear, northern flying squirrel), use it for nesting (e.g., dusky-footed woodrat), feed on prey associated with tanoak (e.g., fisher), or use cover provided by dense tanoak in the understory (e.g., Allen's chipmunk and deer mouse). Use of tanoak by birds can include all of the above examples.

The relative dependence of these species of wildlife on tanoak remains an open question. Although these species were more abundant in stands with higher tanoak volume, some may have been using tanoak opportunistically. Well-designed experiments, involving demographic studies of species before and after removal of tanoak, will be necessary to establish causal links between these wildlife populations and the volume of tanoak.

Until such studies are completed, I believe the available evidence is sufficient to recommend maintaining mature tanoak in forest stands, and maintaining some proportion of cutover forest in a tanoak-dominated, brushy condition. Mature

Table 4--Summary of discriminant analyses comparing habitat characteristics between capture and noncapture trapsites of 4 mammal species on 21 study grids (clearcut plots' excluded) in 1982.

	Deer Mouse (N = 387)		Pinyon Mouse (N		Dusky-footed Woodrat (N = 60)		Allen's Chipmunk (N = 193)	
Characteristic[1]	F	Corr.	F	Corr.	F	Corr.	F	Corr.
Bare Ground[2]	6.5	0.20	11.8***	0.46	2.1	0.17	0.6	0.06
Litter	40.2***	-0.51	0.5	-0.09	2.0	-0.16	82.8***	0.71
Logs[3]	24.3***	0.39	3.5	-0.25	2.7	0.19	69.1***	0.65
Herbs, grasses, low shrubs	36.2***	0.48	2.2	0.20	5.6*	0.28	0.0	0.00
Tanoak <2 m	87.2***	0.75	6.5*	0.34	38.8***	0.73	44.8***	0.52
Other <2 m	0.8	0.07	36.9***	0.81	15.4***	0.46	7.0**	0.21
Total 52 m	4.8*	-0.18	3.6	-0.25,	1.8	-0.16	12.3***	0.27

[1]Percent cover of each category, estimated within a 25-m^2 quadrat around a trap.
[2]Includes rocks and area occupied by tree stems.
[3]Downed wood > 8 cm diameter.

forest stands and old, brushy clearcuts seem to be particularly important seral stages for wildlife. Brushy clearcuts dominated by tanoak provide nesting substrate, mast, and hiding cover for small mammals and probably birds. Mature stands with tanoak understories provide foraging habitat for birds and produce logs that are used by amphibians (and probably small mammals). Such stands have the multilayered structure that produces the microclimate required by spotted owls (Barrows 1981) and other birds.

ACKNOWLEDGMENTS

These studies were funded by the Pacific Southwest Region and the Pacific Southwest Forest and Range Experiment Station of the USDA Forest Service. The University of California (AES Project 3501 MS) also provided support. I am indebted to many field assistants, in particular John Brack, Cathy Taylor, and Kenneth Rosenberg who also helped analyze data. I thank Kenneth Rosenberg and William Block for comments on an earlier draft of this paper.

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Preserving Oak Woodland Bird Species Richness: Suggested Guidelines from Geographical Ecology[1]

R. Chad Roberts[2]

Abstract: Recommendations are given for preserving the richness of oak woodland bird communities, based on a theory of "geographical ecology." The theory is tested with preliminary data along a geographical gradient in northwestern California. Results of the test are consistent with the theory, suggesting that it may be useful for predicting effects of habitat fragmentation.

This symposium asks us to consider the effects upon wildlife of human use of oak woodlands. This is similar to questions asked of conservation biologists in designing "nature reserves" to maximize species preservation with a land base shrinking due to human modifications (Whitcomb and others 1981, Harris 1984). An important theoretical framework for nature reserve design has been contributed by students of biogeographic phenomena, in a subject area appropriately termed "geographical ecology." Recently the term "landscape ecology" (Forman and Godron 1986) has been applied to this body of theory.

The theory of "island biogeography" (MacArthur and Wilson 1967) predicts that the species richness of a mainland will be greater than that of a nearby island, and that as the distance of the island from the mainland increases, the richness will decline further. Taking a series of islands of about the same size and with similar habitats, but differing in distance from the mainland species "source pool," the theory predicts a characteristic declining species richness curve as distance increases.

The "Foothill Woodland" (Munz and Keck 1973) habitat type occupies a significant area around California's central valley (the approximate areal distribution may be determined by superimposing the ranges of valley oak and blue oak [scientific names of oaks in table 1] from Griffin and Critchfield 1976). This physiognomically-designated habitat varies somewhat throughout the state, but the avifauna is relatively constant throughout. The breeding species I observed in Yolo County also were described by Verner and Ritter (1985) from Fresno County.

In this paper, I assume that this expanse of Foothill Woodland may be treated as a "mainland," with a species pool that acts as a source of colonists for outlying "islands" of similar habitat. These islands are oak woodland patches within a matrix of different habitats, located in a transect toward the northwest (see fig. 1). The theory predicts that the fraction of the species present at each site that are also found in the mainland pool will decrease with increasing distance of the site from the mainland. However, if any isolated patch is connected to a less isolated patch by a corridor of suitable habitat, then the species richness of the two patches should be similar, and the isolation effect should be less significant.

In this paper I apply geographical ecological theory and preliminary field survey results to examine a pattern of distribution in the breeding avifauna of oak woodlands in northwestern California. My objectives are: (i) to describe the avifaunal similarity among the study sites, (ii) to apply the similarity calculations to test a prediction derived from geographical ecology, and (iii) to explore the application of geographical ecology to the conservation of biological diversity in California's oak woodlands. The theory may be useful in defining the parameters of "nature reserves" in oak-dominated landscapes, or in guiding research efforts aimed at determining the effects of oak woodland fragmentation.

METHODS

Study Sites

The site selected to represent conditions in Foothill Woodland is in western Yolo County, near the end of County Road 29 (see fig. 1), described in Roberts (1976) and hereafter called the Road 29 site. The approximate northwestern limit of Foothill Woodland in the study area is the headwaters of the main and east forks of the Russian River (fig. 1). Foothill Woodland (represented here by the Road 29 data) is the biogeographic "mainland" for this analysis.

The remaining sites discussed in this analysis were selected according to map location and gross habitat conformation. For the study to be meaningful, the habitats being contrasted must be generally similar, and consequently I selected woodland patches dominated by deciduous oak species with little conifer canopy. (The quantitative similarity of the sites and its effect on the birds will be reported in a subsequent paper; as an indication of similarity, oak species present at each site are listed in table 1.) Sites were not selected by "island" size, although the minimum size accepted was 10 hectares (200 meters by 500 meters).

[1]Presented at the Symposium on Multiple-Use Management of California's Hardwood Resources, November 12-14, 1986, California Polytechnic State University, San Luis Obispo, California.

[2]Environmental Analyst, Oscar Larson & Associates, Eureka, California.

Table 1--Oak species found at study sites referred to in this report.

SPECIES	LOCATION						
	Road 29	Round Valley	Eel River	Kekawaka Creek	Olsen Creek	Madden Creek	Bald Hills
Valley Oak (Quercus lobata)	x	x					
Blue Oak (Quercus douglasii)	x	x					
Interior Live Oak (Quercus wizlezenii)	x		x	x			
Black Oak (Quercus kelloggii)		x	x	x	x	x	
Garry Oak (Quercus garryana)			x	x	x	x	x

Adequate spacing along the geographical gradient was required. This was accomplished by fixing the northwestern end of the transect at a known woodland site (the Bald Hills), and locating a second site (Madden Creek) with appropriate size and habitat conformation along the geographical transect. These two sites established an approximate intersite distance of 30 kilometers as the appropriate spacing.

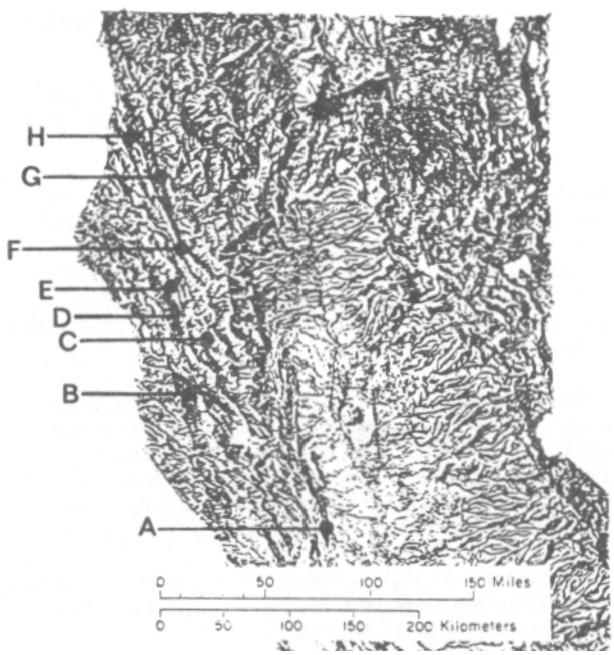


Figure 1--Sites referred to in this report are: A - Road 29, Yolo Co. (Sacramento River drainage); B - headwaters of the Russian River (approximate limit of Foothill Woodland), Mendocino Co.; C - Round Valley, Mendocino Co. (Middle Fork Eel River); D - Eel River canyon, Mendocino and Trinity Cos.; E - Kekawaka Creek, Trinity Co. (mainstem Eel River); F - Olsen Creek, Trinity Co. (Mad River); G - Madden Creek, Humboldt Co. (Trinity River); and H - Bald Hills, Humboldt Co. (Redwood Creek). Note northwest-trending mountains and river drainages, which act as movement corridors for wildlife. Map courtesy of U.S. Geological Survey; reproduced from Griffin and Critchfield (1976).

I required the transect to pass through the mainstream Eel River valley, and include Round Valley, which is slightly upstream on the Middle Fork. Sites there and at Kekawaka Creek are approximately at opposite ends of an essentially continuous oak woodland corridor through the Eel River canyon. The final site (Olsen Creek) was selected as an appropriately configured woodland patch that lay within a map circle between the two adjacent sites.

The oak woodland corridor along the mainstream Eel River was sampled by automobile where accessible, and by boat in the area downstream of Dos Rios (confluence of the mainstream and Middle Fork). Most of this river reach is inaccessible by automobile.

Bird Species Richness

Bird species richness as used here is the number of species believed to be breeding at each site. I assumed that the habitat conformation at each site is close enough to the "niche gestalt" (James 1971) of each species to be acceptable habitat, and that each species is experiencing adequate reproduction to maintain breeding populations in northwestern California. "Breeding" is defined here as being present for one month or longer during the period March through July, being observed defending a territory, or being observed with young. This definition purposely avoided the time-consuming process of locating nests, allowing species to be included on the basis of behavior that generally accompanies breeding. Examples of such behavior include territorial advertisement (especially regular singing), countersinging, conspecific chasing, carrying nesting material, and frequent foraging forays with food ferried back to near the starting point. Many species observed on the study sites were excluded from this analysis because they did not meet any of the criteria for inclusion.

The species richness for Road 29 is based upon a spot-map breeding survey conducted in the spring of 1978; all breeding species present were identified.[3]

The Kekawaka Creek data were derived from an intensive 2-day (12-hr) survey conducted in September 1982. An irregular transect 14.8 kilometers long was walked, in which all bird species present were recorded. The assignment of breeding status to a subset of the observed species (table 2) was based on the following criteria: (i) species that are widespread breeders in northwestern California, (ii) species that are resident (i.e., nonmigratory) in the region, and (iii) species that I have observed breeding in other oak-dominated sites in the Eel River basin (see discussion).

Quantitative data for Round Valley were derived from one preliminary survey conducted outside the breeding season in August 1986. A 1-km survey transect was walked (both directions); additional spot surveys extended the survey length to approximately 2.5 km. All observed bird species were listed, although the primary focus was scansorial species (see below). I used the same criteria that were used for Kekawaka Creek to assign breeding status.

Bird species occurring in oak stands within the Eel River canyon were recorded during three canoe trips (1983, 1984, and 1985), and supplemented with additional data from the part of the canyon accessible by automobile. The canoe trips were conducted in may and June, when nearly all bird species encountered are breeding. Notes were made of all bird species seen or heard in oaks along the river. In addition, variable circular-plot counts (see below) were conducted at several locations.

Data for the other three locations (Bald Hills, Madden Creek, and Olsen Creek) were derived from variable circular-plot surveys (VCP; Reynolds and others 1980), done in conjunction with walkthrough surveys used to identify all species present at each site (see table 3). Additional data for the Bald Hills site came from Davenport (1982). VCP surveys were conducted between 08:00 and noon during the breeding seasons of 1985 and 1986. Sampling periods were standardized at 8 minutes each. Because I was the sole observer, variability in observer sensitivity should be minimized.

VCP count points were not permanently marked. Repeat counts at each of the three sites were conducted from approximately the same points (differing by a few meters between counts) on different visits. Similarly, the walkthrough surveys covered approximately the same zigzag route during sequential visits to a site.

The preliminary species richness data for these sites clearly only approximate the breeding avifauna of each site (see discussion). To strengthen hypothesis testing described here, I took special care to identify scansorial species (which forage partly or entirely on or beneath the bark on trunks, branches, and limbs of the oaks) present at each site. These species are essentially resident (i.e., occur all year) in the woodlands. If geographic trends for the scansorial guild are similar to the trends for all species, then interpretations for the entire avifauna can be made with greater confidence.

[3] Roberts, data on file, Eureka, California.

RESULTS AND DISCUSSION

Biogeography

Few species occurred along the entire gradient. Most species found breeding in northwestern California oak woodland patches did not breed at Road 29, and vice versa (table 2). Using the Road 29 site as a standard for the breeding avifauna of the "mainland," the relative dominance of the mainland species at each of the other sites can be expressed as a ratio according to the formula:

$$D = B/T,$$

where: D = the index of relative dominance,

B = the number of species that bred both at Road 29 and at the site being compared with Road 29, and

T = the total number of species that bred at the site being compared with Road 29.

The descending curve obtaining by plotting the index of relative dominance against site (in order of distance from Road 29; fig. 2A) compares favorably with the "extinction" curves of the MacArthur-Wilson model (MacArthur and Wilson 1967), suggesting a biogeographic interpretation of the decreasing index.

The number of species breeding in any woodland patch did not decrease with distance from Road 29 (table 2), but the percentage of species at each site that were the same as those at Road 29 did (fig. 2A). Thus, as "mainland" pool species dropped out of the local avifauna, they were

Table 3--Numbers of visits, numbers of variable circular-plot counts, and range of percent of species detected at study locations referred to in this report.

Site	Number of Visits	Number of VCPs	Percent of Species Detected[1]
Round Valley	2	2	40 - 50
Eel River Canyon	5	7	65 - 80
Kekawaka Creek	3	-	-
Olsen Creek	4	8	67 - 82
Madden Creek	8	13	75 - 90
Bald Hills	3	6	62 - 78

[1] Based on bootstrap estimation curves in figure 4 of Verner and Ritter (1985).

Table 2--Breeding bird species found at study sites referred to in this report.

SPECIES	LOCATION						
	Road 29	Round Valley	Eel River Canyon	Kekawaka Creek	Olsen Creek	Madden Creek	Bald Hills
American Kestrel (*Falco sparvarius*)	x[1]	x	x	x	x		x
California Quail (*Callipepla californica*)	x	x	x	x			
Mountain Quail (*Oreorty pictus*)				x			
Mourning Dove (*Zenaida macroura*)	x					x	
Anna's Hummingbird (*Calypte anna*)	x						
Allen's Hummingbird (*Selasphorus sasin*)			x	x			
Acorn Woodpecker[2] (*Melanerpes formicivorus*)	x	x	x	x	x	x	
Nuttall's Woodpecker[2] (*Picoides nuttalii*)	x						
Downy Woodpecker[2] (*Picoides pubescens*)				x	x	x	x
Hairy Woodpecker[2] (*Picoides villosus*)		x	x	x	x	x	
Northern Flicker[2] (Colaptes auratus)		x	x		x	x	x
Western Wood-Pewee (*Contopus sordidulus*)			x	x			x
Western Flycatcher (*Empidonax difficilis*)			x	x		x	
Ash-throated Flycatcher (*Myiarchus cinerascens*)	x	x	x				
Western Kingbird (*Tyrannus verticalis*)	x		x				
Steller's Jay (*Cyanocitta stelleri*)		x	x	x	x	x	x
Scrub Jay (*Aphelocoma coerulescens*)	x	x	x	x		x	
Chestnut-backed Chickadee[2] (*Parus rufescens*)			x		x	x	x
Plain Titmouse[2] (*Parus inornatus*)	x	x	x	x			
Bushtit (*Psaltriparus minimus*)	x	x	x			x	
Red-breasted Nuthatch[2] (*Sitta canadensis*)					x?[1]	x	x?
White-breasted Nuthatch[2] (*Sitta carolinensis*)	x	x	x	x		x?	x?
Brown Creeper[2] (*Certhia americana*)					x?		
Bewick's Wren (*Thryomanes bewickii*)	x			x		x	
Bluegray Gnatcatcher (*Polioptila caerulea*)		x	x			x	
American Robin (*Turdus migratorius*)					x	x	x
Solitary Vireo (*Vireo solitarius*)		x	x	x	x	x	x
Hutton's Vireo (*Vireo huttoni*)						x	
Warbling Vireo (*Vireo gilvus*)					x	x	
Orange-crowned Warbler (*Vermivora celata*)			x		x	x	x
Yellow-rumped Warbler (*Dendroica coronata*)					x	x	

Table 2--continued

SPECIES	LOCATION						
	Road 29	Round Valley	Eel River Canyon	Kekawaka Creek	Olsen Creek	Madden Creek	Bald Hills
Black-throated Gray Warbler (*Dendroica nigrescens*)			x	x	x	x	
MacGillivray's Warbler (*Oporornis tolmiei*)					x	x	
Western Tanager (*Piranga ludoviciana*)		x	x		x		
Black-headed Grosbeak (*Pheucticus melanocephalus*)			x	x	x	x	x
Rufous-sided Towhee (*Pipilo erythropthalmus*)			x	x		X	x
Brown Towhee (*Pipilo fuscus*)	x	x	x	x			
Chipping Sparrow (*Spizella passerina*)					x	x	
White-crowned Sparrow (*Zonotrichia leucophrys*)							x
Dark-eyed Junco (*Junco hyemalis*)							x
Western Meadowlark (*Sturnella neglecta*)	x						x
Northern Oriole (*Icterus galbula*)	x		x		x?		
House Finch (*Carpodacus mexicanus*)	x						
Lesser Goldfinch (*Carduelis psaltria*)				x			x
American Goldfinch (*Carduelis tristis*)						x	
SITE TOTAL	17	15	25	20	20	26	17

[1]"x" represents a species known or highly likely to be breeding at a site. A blank indicates that the species was not observed or is considered unlikely to breed at site. "x?" represents a species present during the breeding season, but without adequate data to confirm breeding (primarily used here for scansorial species).

[2]Scansorial species.

replaced by other species. A comparison of species in table 2 with those in Marcot (1979) suggests that the added species are commonly found in mixed-evergreen forest, the plant community that largely composes the habitat matrix in northwestern California. The declining curve (fig 2A) of mainland species suggests that the "island" approach is reasonable: species in the "mainland" source pool occur as if the intervening habitat were unsuitable.

A similar geographic shift was observed in the composition of the scansorial guild (fig. 2B). The Kekawaka Creek similarity to Round Valley at the other end of the corridor is suggestive (also see table 2), supporting the hypothesis of a "corridor effect." Because the species in this guild are essentially permanent residents, it appears that the turnover indicated for the avifauna as a whole (fig. 2A) was not due solely to regular migration fluxes, but reflects a real geographic pattern.

The percentage of species in each oak woodland patch that are members of the scansorial guild was relatively constant (fig. 2C). I speculate that similar habitat structures in these deciduous oak woodlands lead to relative constancy in the proportion of species that forage by scanning limbs and trunks. The most likely reason is that the distribution of foraging substrate, and the consequent prey distributions, are very similar among the sampled sites (see Holmes and Recher 1986 for a discussion of how substrate availability may determine avian community similarity); ecological mechanisms producing the pattern, however, are far from clear.

The means by which members of a bird community ensure coexistence have been the subject of considerable study and discussion (Cody 1974, Diamond 1975, Simberloff 1978, and others). Explaining the coexistence of these species would carry the geographical analysis one step further. The determinants of community structure are

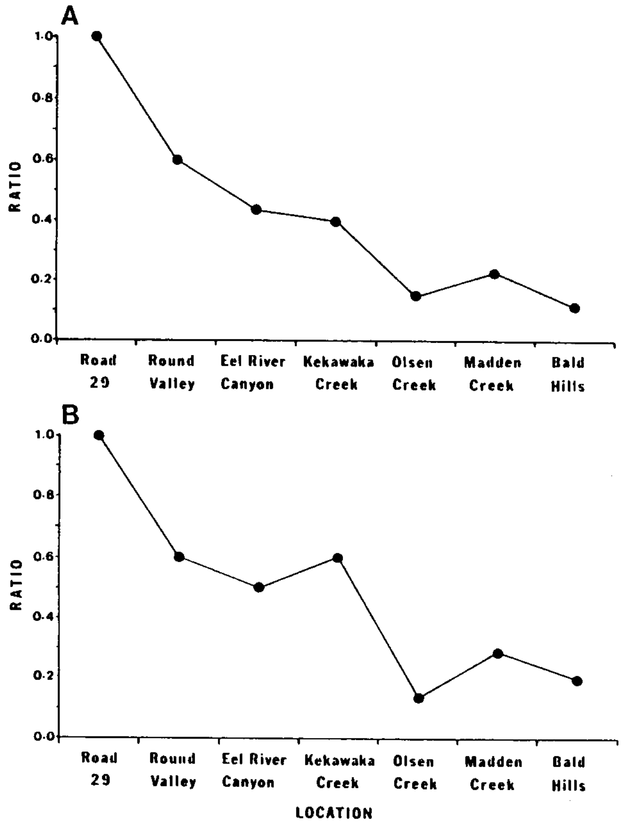
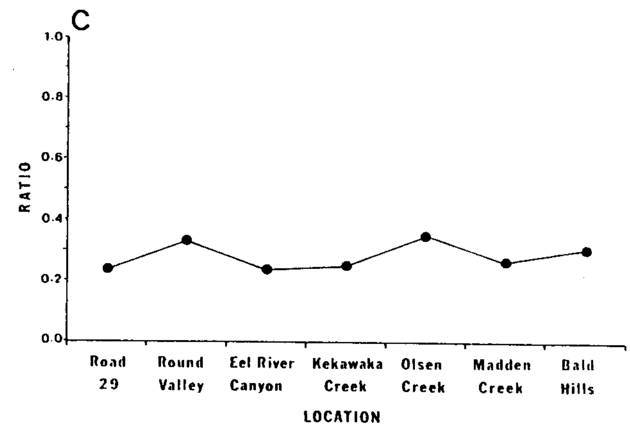


Figure 2--Trends in species' occurrences.
A. Ratio of the number species found at both Road 29 and each site to the total species count at the site being compared with Road 29.
B. Ratio of the number of scansorial species found at both Road 29 and each site to the total count of scansorial species at the site being compared with Road 29. C. Ratio of the number of scansorial species at each site to the total species count at that site.



unknown for any of these woodlands; oak woodland avifaunas may be an excellent subject for such studies.

These preliminary results probably do not present a completely accurate portrayal of breeding bird species richness in northwestern California oak woodlands. The survey results are not used here to assess densities, however, but only to summarize species' occurrences. Excluding Round Valley, the numbers of VCP counts (table 3) for each site suggest that the VCP counts alone should have detected at least 56 percent of the species present (based on the figure 4 curves of Verner and Ritter 1985). The walkthrough surveys disclosed additional species in each case, so that it is likely that most of the breeding species were observed in these woodlands.

The method I used to designate breeding species for the Kekawaka Creek and Round Valley sites should tend to overestimate the fractions of the observed avifauna that breed at these sites. Even though most of the species have been observed to breed in oak woodlands in northwestern California, they might not breed at these two sites. This result would change the values in the centers of the figure 2A and 2B curves, but the overall shape of the curves would remain the same, and the theoretical considerations would be unchanged.

The objectives of this paper involve testing the applicability of a theory. I believe that the reported data are adequate for this use. More exact results will follow from additional field studies, but I anticipate that the general trend reported here will remain. The similarity in the relative dominance curves (figs. 2A and 2B) for the relatively inexact total species sample and the more accurate scansorial species sample along the geographical gradient suggests applying the theory to preserving diversity in oak woodlands.

Applying Ecological Theory to Oak Conservation

Recommendations for managing and conserving California's oak woodland heritage should be based on bodies of theory recognized by the scientific community. Such a body of theory is landscape ecology, incorporating the concepts of geographical ecology. This theory has implications for managing California's oak woodlands, especially the "hardwood rangelands" around the Central Valley.

"Habitat fragmentation" refers to the effects of removing parts of a once-continuous habitat matrix. Evidence indicates that fragmentation reduces the numbers of species and individuals initially found in a habitat (Whitcomb and others 1981, Harris 1984). The effect of fragmentation on species differs according to each species' ecology. Theoretical considerations and empirical evidence suggest that large habitat fragments support more species than do small fragments (Pickett and Thompson 1976, Whitcomb and others

1981). In some habitats, certain species require a "minimum" habitat area (Forman and others 1976). I know of no study that has addressed the effects of fragmentation or minimum patch size for any plant or animal species in California oak woodlands. Apparently one guideline for conserving diversity in these woodlands might be that fragments should be as large as possible.

A related concept addresses the "connectedness" of fragments. Suitable habitat corridors or "bridges" connecting two or more fragments allow species to move among fragments. It should be relatively easy to preserve connections among patches, and I suggest this as a second guideline. Shelterbelts or "hedgerows" along fencelines, remnant woodlands on steep or rocky areas, riparian corridors, and similar habitat features do not significantly reduce the utility of an area of grazing land. Indeed, they should assist landowners in maintaining land productivity and water quality; Raguse and others (in press) recommended retaining habitat remnants for precisely these reasons.

Evidence and theory also indicate that avian species richness in an area increases as a function of habitat diversity in two ways. First, vertical (Sabo and Holmes 1983, Holmes and Recher 1986) and horizontal (Roth 1976) foliage diversity are positively correlated with the number of bird species found at a site. The number of bird species present also increases with the number of plant species present (James and Warner 1982). Second, changes in the habitat along an environmental gradient lead to an overall increase in diversity (Lack 1971, 1976), a phenomenon called "beta diversity" (Whittaker 1975). I suggest as a management guideline that habitat remnants have as great a diversity as possible, in terms of the spatial distribution of habitat elements. In woodlands with several oak (and nonoak) species present, a proportional representation of all species should be retained. Where an area under management consideration has a variety of habitat subtypes (savannah, riparian corridor, closed-canopy woodland, and/or chaparral), appropriately-sized remnants of all types should be retained. Vertical foliage distributions in the remnants should be similar to those of the original woodland.

In summary, recommended guidelines for preserving the richness of avian species breeding in California's oak woodlands are: (i) maintain large habitat patches, (ii) maintain connections among the patches, and (iii) maintain structural diversity within the patches. Available data do not indicate which guideline is the most (or least) important in California; managers should implement all three to the greatest degree possible. I suspect that the third guideline represents the greatest contrast to existing management, and in the short term it may be appropriate to emphasize management actions (such as temporary exclusion from grazing) that promote increased habitat structural diversity.

These guidelines for preserving biological diversity are based on existing ecological theory and empirical knowledge. A more comprehensive review and attention to complete theoretical treatments (e.g., Pickett and Thompson 1976, Forman and Godron 1986) undoubtedly will lead to additional guidelines. Additional research effort should be focused upon the ecological mechanisms that underpin biogeographic theories. Such theories have been applied to preserving biological diversity in other contexts, and their application to California's hardwood rangelands can only strengthen resulting management guidelines. Patch sizes, connectedness, and spatial distribution are not trivial considerations for Foothill Woodland plant and wildlife habitats being subjected to firewood harvests, rangeland conversions, and residential subdivision development. I recommend that decisionmakers not make many long-term commitments that would further fragment hardwood resources in California until the impacts of such actions have been studied adequately.

ACKNOWLEDGMENTS

I thank Nancy Tilghman, Ron LeValley, and especially Jerry Verner for helpful comments on this manuscript.

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Use of Pacific Madrone by Cavity-Nesting Birds[1]

Martin G. Raphael[2]

Abstract: As part of a larger study of wildlife habitat associations in Douglas-fir (Pseudotsuga menziesii) forests of northwestern California, I recorded characteristics of nest sites used by 16 species of cavity-nesting birds. Pacific madrone (Arbutus menziesii) contributed only 8 percent of the basal area of the stands I studied, but 24 percent of all cavity nests were in madrone. Although nests were distributed among 17 tree species, only madrone was used at a rate greater than predicted from availability. About 75 percent of available madrone trees were <30 cm dbh, but only 11 percent of the nests were in these smaller trees. Larger than average madrones seem to be an important habitat component for cavity-nesting birds in California's Douglas-fir forests; however, madrones are also a prime fuelwood species. A potential conflict thus exists between commercial use of madrone and its value for wildlife.

Mixed-evergreen forests of northwestern California support one of the most complex vegetation patterns in North America (Whittaker 1961). Much of this complexity results from the diversity of hardwood species comprising the lower overstory canopy. These hardwoods are recognized as a potentially rich resource for wood products and energy (McDonald 1983, Zerbe 1985). Pacific madrone (Arbutus menziesii) is a dominant tree species in this complex and, because of its values as pulpwood and fuelwood, is heavily used locally.

Pacific madrone is also an important food source for birds and other species that feed on its berries. For example, Hagar (1960) found that varied thrushes (Ixoreus naevius) were more abundant in a winter when there was a large berry crop than in years of poor crops. I observed a similar response of varied thrushes and American robins (Turdus migratorius) to changing berry crops: both species were at least twice as abundant in the winter of 1980-81 when the madrone berry crop was heavy compared with the next two winters when berries were much less numerous (Raphael, unpublished data).

The importance of Pacific madrone as nesting habitat is less well known. The objective of this study was to evaluate the use of madrone as a nesting substrate for cavity-nesting birds.

STUDY AREA

This study was conducted from 1981 to 1983 in the Six Rivers, Shasta-Trinity, and Klamath National Forests of northwestern California as part of a larger study of habitat associations of vertebrates in relation to stand age (Raphael 1984). Elevation on the study sites ranged from 427 to 1220 m. Weather was characterized by cool, wet winters (89-137 cm precipitation/yr) and warm, dry summers (maximum temperature usually <35°C). Douglas-fir (Pseudotsuga menziesii) in association with tanoak (Lithocarpus densiflorus) and Pacific madrone dominated the forest cover.

METHODS

During the course of other field work in spring and summer, observers located active bird nests. For each active nest, the observer noted the date, location, bird species, tree species, tree condition (live or dead), tree height, dbh, nest height, nest aspect, substrate type (if the nest was not in a tree), nest status (building nest, incubating eggs, feeding young), and any other relevant observations.

To characterize the structure and composition of vegetation in the study area, 408 0.04-ha circular plots were randomly located. Species, height, dbh, and crown dimensions of each tree or shrub >2.0 m tall within each plot were recorded. These data were used to calculate canopy volume for each species on each plot. The program HTVOL (Mawson and others, 1976) was modified to perform all such volume calculations.

[1]Presented at the symposium on Multiple-Use Management of California's Hardwood Resources, November 12-14, 1986, San Luis Obispo, California.

[2]Research Wildlife Biologist, Rocky Mountain Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture, Fort Collins, Colorado, stationed in Laramie, Wyoming.

Table 1--Abundance of dominant trees in Douglas-fir forest of northwestern California. Values are means from 408 0.04-ha plots.

Species	Density (stems/ha)	Basal area (m^2/ha)	Canopy volume (m^3/ha)
Douglas-fir	325.8	37.1	48,138
Tanoak	460.0	8.4	12,874
Pacific madrone	57.8	4.8	3,406

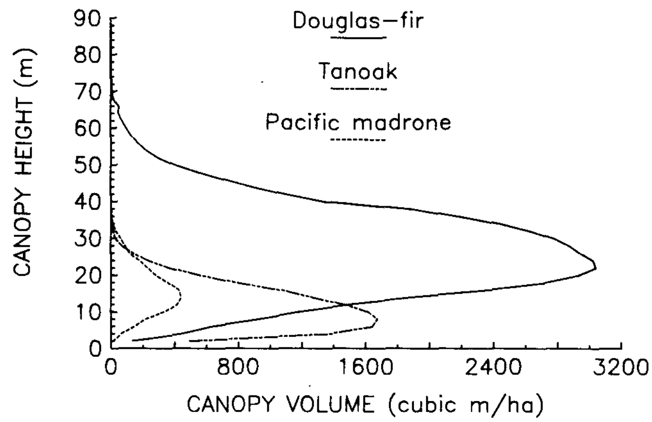

Figure 1. Canopy volume in relation to height of three tree species in Douglas-fir forests, northwestern California. Values at each height are averages from all tree sampled on 408 0.04-ha plots.

RESULTS

Madrone Characteristics

In all, 25,110 trees and shrubs of 37 species on the 408 vegetation plots were sampled. Pacific madrone ranked third in average density, basal area, and canopy volume after Douglas-fir and tanoak (table 1). Madrone occurred as a relatively minor component of the lower canopy in association with tanoak; both species were overtopped by Douglas-fir (fig. 1). Canopy volume of madrone was distributed below about 30 m canopy height, reaching its maximum volume at about 15 m (fig. 1). Madrone was most abundant on drier, south-facing slopes at lower elevations. Its abundance was significantly correlated ($P < 0.001$) only with canyon live oak (*Quercus chrysolepis*), suggesting that the two species have similar habitat requirements.

Nest Tree Characteristics

Observers located 126 nests of 33 bird species (table 2). Overall, most nests were in Douglas-fir, followed by Pacific madrone and tanoak. Among 70 cavity nests, 35 were in Douglas-fir, 17 in Pacific madrone, 7 in tanoak, 3 in *Quercus* species, and 8 in other species. The frequency of cavity nests in Pacific madrone was significantly greater (binomial test, $P <$ 0.001) than the relative basal area of madrone

Table 2--Tree species used for nesting by cavity-nesting and other bird species in Douglas-fir forests of northwestern California.

Bird Species	Numbers of nests by species[1]					
	DF	PM	TO	QS	OT	Total
Western screech-owl (*Otus kennicottii*)	1	0	0	1	0	1
Spotted owl (*Strix occidentalis*)	1	0	0	0	0	1
Acorn woodpecker (*Melanerpes formicivorus*)	1	2	0	0	0	3
Red-breasted sapsucker (*Sphyrapicus ruber*)	5	6	0	0	2	13
Downy woodpecker (*Picoides pubescens*)	0	1	1	0	0	2
Hairy woodpecker (*Picoides villosus*)	0	3	0	0	1	4
White-headed woodpecker (*Picoides albolarvatus*)	1	0	0	0	0	1
Northern flicker (*Colaptes auratus*)	2	0	2	0	1	5
Pileated woodpecker (*Dryocopus pileatus*)	1	0	0	0	1	2
Mountain chickadee (*Parus gambeli*)	0	1	0	0	1	2
Chestnut-backed chickadee (*Parus rufescens*)	6	0	0	1	0	7
Red-breasted nuthatch (*Sitta canadensis*)	8	1	1	2	1	13
White-breasted nuthatch (*Sitta carolinensis*)	1	0	1	0	1	3
Brown creeper (*Certhia americana*)	7	0	1	0	0	8
House wren (*Troglodytes aedon*)	1	2	1	0	0	4
Western bluebird (*Sialia mexicana*)	0	1	0	0	0	1
All cavity-nesters	35	17	7	3	8	70
Other birds (17 species)	12	4	13	2	25	56
All species	47	21	20	5	33	126

[1]DF = Douglas-fir, PM = Pacific madrone, TO = tanoak, QS = Quercus species, OT = other tree or shrub species

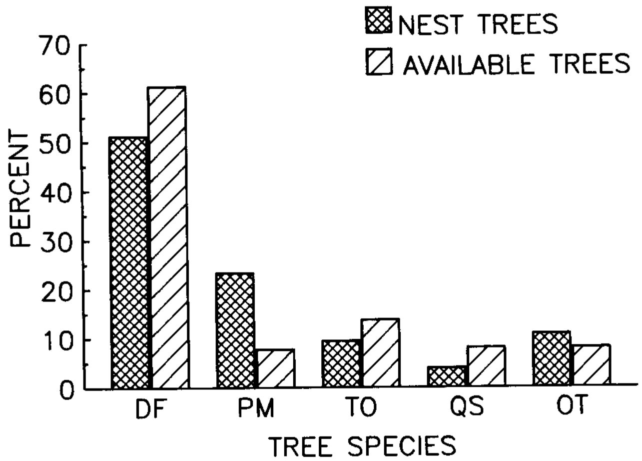

Figure 2. Percent use by cavity nesting birds and percent availability of tree species. DF = Douglas fir, PM = Pacific madrone, TO = Tanoak, QS = Quercus species, OT = other.

(fig. 2); frequencies of cavity nests in all other tree species did not differ significantly from availability. Open-nesting species, in contrast, used tanoak at a rate significantly greater than expected (35.1 percent of nests versus 14.0 percent basal area, $P < 0.01$).

Among primary cavity-nesting species (those capable of excavating their own nest cavities), red-breasted sapsucker, hairy woodpecker, and acorn woodpecker most often excavated cavities in madrone (table 2). Together, these three species excavated 11 of 17 nests in madrone whereas only 2 madrone nests would be expected if nest selection were random with respect to tree species. Two of these species, red-breasted sapsucker and hairy woodpecker, are the most abundant woodpeckers in the Douglas-fir habitat type (Raphael and others, in press), and their apparently strong preference for Pacific madrone may result in a higher proportion of abandoned cavities (suitable for secondary cavity-nesting species) in madrone versus other tree species.

Trees used by cavity-nesting birds were most frequently in the 30- to 45-cm diameter class (25 percent of all nests). In contrast, most sampled trees were <15 cm dbh (75 percent). Among cavity nests in Pacific madrone, 89 percent were in trees >30 cm dbh, whereas only 22 percent of available trees were that size (fig. 3). Madrones used by cavity-nesting birds averaged 14.9 m tall (range 6.0-44.0, SD=10.2 m); nest holes averaged 9.0 m above the ground (range 3.0-15.0, SD=3.4 m). Nine of the 17 madrone nest trees were live, and five of these trees showed no external evidence of disease or damage.

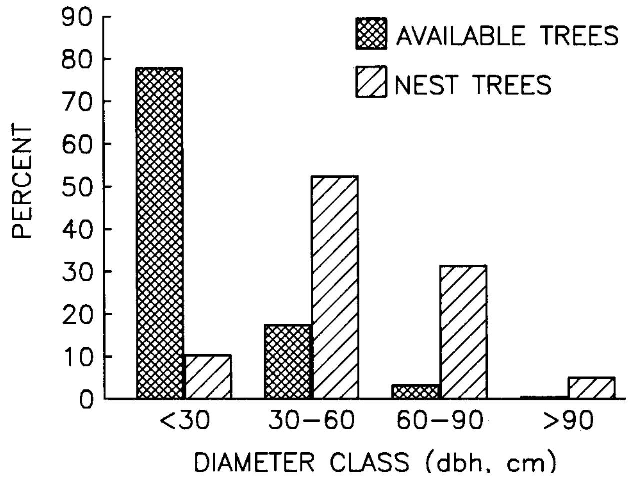

Figure 3. Diameter distribution of madrones used for nesting (n=19) and of available madrones (n=1,061) in northwestern California.

DISCUSSION

Although sample sizes of nests are small, these data suggest that Pacific madrone is an important component of cavity-nesting bird habitat in Douglas-fir forests of northwestern California. The importance of madrone in this study area seems to parallel the importance of aspen (Populus tremuloides) in the northeastern U.S. (Lawrence 1967), especially for hairy woodpecker and sapsucker populations. Aspen and madrone are similar in form: both are smooth barked, both tend to have long trunks that are relatively free of branches, and their wood is similar in texture and hardness.

More important, perhaps, is the frequency of heartwood decay fungi associated with both species. Woodpeckers are known to select aspen infected with Fomes igniarius (Kilham 1971). By leaving the sapwood sound while decaying the heartwood, this fungus creates ideal conditions for excavating a nest cavity surrounded by a strong outer wall. The presence of decay within madrone nest trees was not noted, but I have observed a high incidence of heartrot in cut madrones, especially among larger-diameter trees such as those preferred by birds in this study. I believe it is likely that birds in northwestern California select trees that are infected by heartrot fungi. This may explain the apparent preference for madrone and the high incidence of nests located in live trees, unlike other areas in California where dead trees are the preferred substrate (Raphael and White 1984).

Management Recommendations

If Pacific madrone is a preferred nest tree species for primary cavity-nesting birds in this forest type, some considerations should be given

Table 3--Estimated breeding densities of primary cavity-nesting bird species and estimated numbers of Pacific madrone stems >30 cm dbh needed each year to provide nesting substrate.

Woodpecker species	Maximum density (D) (pairs/100 ha)[1]	No. cavities excavated/ pair/yr (C)[1]	Proportion madrone (X)[2]	No. madrone stems needed /100 ha (S)[3]
Acorn woodpecker	8.6	5	0.7	30
Red-breasted sapsucker	27.9	1	0.5	14
Downy woodpecker	4.9	2	0.5	5
Hairy woodpecker	39.5	3	0.8	95
Northern flicker	12.0	1	[4]0.1	2
Pileated woodpecker	0.5	3	[4]0.1	1
Totals	93.4			147

[1]From Neitro and others (1985).

[2]Proportion of nests in madrone, rounded from data in Table 2.

[3]Computed from (D) x (C) x (X).

[4]Values assumed.

for its management. Two considerations are most important--the number of trees and their diameter. To estimate madrone requirements, I used data from Neitro and others (1985) and this study to calculate (S) = (D) x (C) x (X) where (S) is the number of madrone stems needed per year, (D) is the maximum density of each primary cavity-nesting species, (C) is the number of cavities excavated/pair/year, and (X) is the expected proportion of nests excavated in madrone. Results indicate that a total of about 147 madrone stems/100 ha (1.5 stems/ha) should be available each year (table 3). As shown in figure 3, birds rarely nested in madrones <30 cm dbh. Thus, the estimated madrone requirement of 1.5 stems/ha should include only trees >30 cm dbh. The average density of these larger madrones in the vegetation plots was about 13 stems/ha. Therefore, meeting these estimated nesting requirements of primary cavity-nesting birds would entail retention of about 10 percent of the available large stems.

These recommendations are offered as interim guidelines. First, it is not known if birds used madrone opportunistically in this study. The critical question is whether, in the absence of madrone, cavity-nesting birds might shift to another tree species without loss of reproductive fitness. Circumstantial evidence presented in this study suggests otherwise: madrone trees seemed to be actively selected by at least two primary cavity-nesting species. Until results of additional research can resolve these questions, retention of madrone in managed stands would seem to be prudent.

ACKNOWLEDGMENTS

I thank the Pacific Southwest Region and the Pacific Southwest Forest and Range Experiment Station of the USDA Forest Service for funding this study. The University of California (AES Project 3501 MS) also provided support and I thank Reginald H. Barrett for his encouragement. The study would not have been possible without the help of many dedicated field assistants; I thank them all. Douglas Runde and James A. Sedgwick commented on an earlier draft.

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Monitoring Herpetofauna in Woodland Habitats of Northwestern California and Southwestern Oregon: A Comprehensive Strategy[1]

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Abstract: Herpetofauna representing 26 species were collected for 2 years from 54 terrestrial and 36 aquatic sites in mixed hardwood-coniferous forest in northwestern California and southwestern Oregon, using three different sampling methods: pitfall traps, time-constrained searches, and area-constrained searches (aquatic habitats only). The advantages and disadvantages of each method are discussed in relation to the research and management goals of data quality, data quantity, cost-effectiveness and applicability to long-term monitoring. A comprehensive approach to herpetofaunal monitoring in woodland habitats is recommended, with emphasis on training of personnel in species identification and habitat preferences, timing of sampling effort with respect to climatic variables, repeatability of sampling, and complementation of sampling methods. Such an approach promotes cost-effective and complete species sampling, accurate relative abundance values, and a versatile, reliable long-term monitoring program.

The important role of herpetofaunas in ecosystem dynamics has become increasingly apparent (Burton and Likens 1975, Bury and others 1980). Consequently, there is considerable research interest in the structure of herpetofaunal communities, both temperate and tropical. These communities contain a broad diversity of life forms, presenting a unique challenge for investigators. The herpetofauna in California hardwood habitats is no exception, consisting of a total of 38 species from 4 orders: 9 salamanders, 5 frogs and toads, 9 lizards, 14 snakes, and 1 turtle. Gathering data on the distribution and abundance of all elements in such a diverse community usually requires a combination of sampling techniques. Several sampling methods have been developed (Scott 1982). However, little information is available to compare the relative effectiveness of different sampling methods in different habitats (Vogt and Hine 1982, Campbell and Christman 1982, Bury and Raphael 1983, and Raphael and Rosenberg 1983). The objectives of this study were to compare (1) the numbers and species composition of herpetofauna, and (2) the relative cost effectiveness, using three methods. This sampling approach was developed for the Forest Service's Old-Growth Wildlife Habitat Program (Corn and Bury, Bury and Corn, in prep.) for use in the Douglas-fir dominated forests of the Pacific Northwest. Data reported here are from the Siskiyou Mountains/Klamath Mountains Province of the Old-Growth Wildlife Habitat Program (CGWHP). These methods are equally applicable in the more xeric and open woodland habitats that are the focus of this symposium.

STUDY AREA

The study was conducted within Douglas-fir (Pseudotsuga menziesii) dominated mixed coniferous-hardwood forests of northwestern California and southwestern Oregon; the southwest portion of the Douglas-fir Biome. Fifty-four terrestrial study sites, ranging in size from 21 to 150 ha, and 39 aquatic study sites (15-m lengths of second- or third-order streams) were sampled. Fifteen terrestrial sites and 12 aquatic sites, were located in each of the following: near Bransconb in Mendocino County, California; near Willow Creek in Humboldt and Trinity Counties, California; and near Cave Junction in Josephine County, Oregon. Three terrestrial sites and one aquatic site were located in each of three additional locations: Butte Creek and Redwood Experimental Forest in Humboldt County, California, and on serpentine formations east of the Kalmiopsis Wilderness Area in Josephine County, Oregon.

METHODS

Three methods were used to sample the species composition and abundance of the herpetofauna: pitfall traps (Corn and Bury, in prep.), time-constrained searches (Corn and Bury, in prep; Raphael and others 1982; Inger and Colwell 1977), and area-constrained aquatic searches (modified from Bury and Corn, in prep.). Two of the methods, pitfall trapping and time-constrained searches, were used to sample terrestrial species, while an area-constrained search method was adapted specifically for aquatic habitat. The aquatic search technique is a modified

[1]Presented at the Symposium on Multiple-Use Management of California's Hardwood Resources, November 12-14, 1986, San Luis Obispo, Calif.

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area-constrained technique that can also be applied to terrestrial habitats, and hence these data are comparable in several ways to data collected with the other two methods.

Pitfall Trapping

Pitfall traps consisted of two no. 10 tin cans taped together with duct tape (bottom removed from upper can) with a plastic funnel insert (1-lb margarine tub with its bottom cut out) to prevent animals from climbing out (fig. 1, Bury and Raphael 1983). Each trap was buried flush with the ground, and a wooden cover (a shingle or piece of bark) was propped up on pebbles or twigs to provide 1-3 cm of crawl space. Grids of 36 traps, spaced 15 m apart in rows and columns of six, were installed at 49 terrestrial sites: 15 grids were established in each of the three areas described above, plus 2 grids each at Butte Creek and at the Redwood Experimental Forest in Humboldt County, California. Traps were operated for 50 days in October and November 1984, and for 30 days in October 1985. Traps were checked at 5- to 7-day intervals, and captures were either taken or marked to prevent them from being recounted on subsequent rounds.

Time-Constrained Searches

Time-constrained searches consisted of a two-person, 2-hour search of as much microhabitat at a site (from ground level up to 2 m) as could be covered in that time, for a total of 4 person-hours per site each year. Workers using potato rakes lifted rocks and woody debris, opened decomposed logs, raked rock rubble and leaf litter, probed cracks, crevices and other refuges, peeled bark, and walked through low vegetation to flush out animals. Only the actual searching time counted against the time limit; measuring of specimens and recording of data were performed with the clock stopped. Searches were performed at each of the 54 terrestrial sites between March and June 1984 and again in 1985. In addition, 15 sites near Branscomb, and 15 sites near Willow Creek were searched between April and June 1986.

Area-Constrained Aquatic Searches

Second- or third-order streams (Strahler 1952) on or near the terrestrial sites were searched. Searchers selected three 5-m reaches 1-3 m wide along each stream by walking 50 paces upstream from the nearest trail or road access for the first reach, and from the top of the previous reach for subsequent reaches (systematic random sampling). The searches required two people capturing animals in the water, and a third person at streamside handling the captures and recording the data. Searchers worked upstream, placing nets behind them, and holding face masks at the water's surface where necessary to improve underwater visibility. They worked systematically and thoroughly, moving all rocks, logs, and debris possible and probing all crevices and other cover to capture all animals within the reach. Twenty-one streams were searched in 1984 and 19 in 1985.

Analysis of Data

Results were compared for individual species, total captures, and mean captures per site from 1984 and 1985 for the three methods. Also, the 1984 and the 1985 data from the two terrestrial sampling methods were compared in terms of both number of individuals captured, and the number of new species present-the first record for a particular species at each study site. Data from TCS, taken on a subset of 30 study sites in 1986, were included in this latter analysis. Finally, a cost analysis was performed for each method, based on total captures and total cost during 1984 and 1985, to arrive at a cost-per-capture figure for each method.

RESULTS

Pitfall Trapping

Pitfall trapping (PF) sampled 19 of the 26 species of herpetofauna collected (table 1). In the first 30 nights of trapping in 1984, 121 fewer individuals were captured than in the first 30 nights in 1985 (table 2). Comparison of numbers of individual captures per trap check indicate a markedly higher rate of capture immediately following the first rains of the season (fig. 1).

The numbers of species-presence records were 133 in 1984 and 101 in 1985, with 161 records noted for both years combined (table 2). During the last 20 trap-nights of 1984, 30 new species-presence records occurred; 24 of these records were unique while 6 were duplicated in the 1985 trap session. The rate of accumulation of new species records for both years combined indicates a leveling off began after about 50 days, but new records continued to accumulate throughout the remaining 30 days (fig. 2). Fifty-nine of the new species present were noted only in 1984, while 28 were unique to 1985 (table 2). These 28 additions occurred on 20 sites, with the range of new species added per site at 0-4, and the mean of new species added per site at 0.55. Operation of the traps for a second year resulted in increasing the new species records by 16.8 percent, an appreciable amount. These data indicate that sampling efforts in excess of 50 days, while recording a lower rate of new species, continue to yield new information on species richness as the rarer species are captured.

Amphibians

PF was effective for sampling terrestrial salamanders, capturing all the species that time-constrained searches (KS) detected (table 1). However, PF sampled few Clouded Salamanders

Table 1--Captures of herpetofauna collected with three methods in woodland habitats of northwestern California and southwestern Oregon in 1984 and 1985.

Species	Pitfall trapping[1] Total	$\bar{X}$[2]	Time-constrained searches[3] Total	$\bar{X}$	Area-constrained aquatic searches[4] Total	$\bar{X}$	Total all methods
Amphibians							
Tailed Frog (*Ascaphus truei*)	9	0.09 ±0.41	3	0.03 ±0.17	487	12.18 ±18.26	499
Western Toad (*Bufo boreas*)	3	0.03 ±0.17	1	0.01 ±0.10	0	0	4
Pacific Treefrog (*Hyla regilla*)	9	0.09 ±0.29	23	0.21 ±0.61	0	0	32
Yellow-legged Frog (*Rana boylii*)	27	0.27 ±1.25	0	0	21	0.53 ±0.96	48
Frog subtotals	48	0.49 ±1.39	27	0.25 ±0.74	508	12.70 ±17.94	583
Percent of total		8.2		4.6		87.1	10.9
Northwestern Salamander (*Ambystoma gracile*)	4	0.04 ±0.25	1	0.01 ±0.96	0	0	5
Clouded Salamander (*Aneides ferreus*)	5	0.05 ±0.22	153	1.37 ±2.09	0	0	158
Black Salamander (*Aneides flavipunctatus*)	20	0.20 ±0.91	24	0.22 ±0.80	7	0.18 ±0.45	51
Arboreal Salamander (*Aneides lugubris*)	1	0.01 ±0.10	0	0	0	0	1
Calif. Slender Salamander (*Batrachoseps attenuatus*)	72	0.74 ±1.58	631	5.84 ±9.94	2	0.05 ±0.22	705
Pacific Giant Salamander (*Dicamptodon ensatus*)	31	0.32 ±0.73	13	0.12 ±0.47	891	22.30 ±18.95	935
Ensatina (*E. eschscholtzii*)	1194	12.18 ±14.92	1105	10.23 ±8.85	0	0	2299
Del Norte Salamander (*Plethodon elongatus*)	213	2.17 ±13.03	193	1.77 ±6.58	0	0	406
Olympic Salamander (*Rhyacotriton olympicus*)	1	0.01 ±0.10	30	0.28 ±1.11	11	0.30 ±1.43	42
Rough-skinned Newt (*Taricha granulosa*)	39	0.39 ±0.97	34	0.31 ±0.86	3	0.08 ±0.27	76
Salamander subtotals	1580	16.12 ±19.27	2184	20.22 ±15.53	914	22.90 ±13.93	4678
Percent of total		33.8		46.7		19.5	87.1

[1] 49 samplings each year.
[2] X=mean per sampling session ± 1 standard deviation.
[3] 54 samplings each year.
[4] 21 samplings in 1984 and 19 in 1985.

Table 1 (continued)--Captures of herpetofauna collected with three methods in woodland habitats of northwestern California and southwestern Oregon in 1984 and 1985.

Species	Pitfall trapping[1] Total	$\bar{X}$[2]	Time-constrained searches[3] Total	$\bar{X}$	Area-constrained aquatic searches[4] Total	$\bar{X}$	Total all methods
Reptiles							
Western Skink (*Eumeces skiltonianus*)	5	0.03 ±0.26	13	0.12 ±0.51	N/A	N/A	18
Northern Alligator Lizard (*Gerrhonotus coeruleus*)	4	0.04 ±0.20	29	0.27 ±0.77	N/A	N/A	33
Southern Alligator Lizard (*G. multicarinatus*)	1	0.01 ±0.10	2	0.02 ±0.14	N/A	N/A	3
Western Fence Swift (*Sceloporus occidentalis*)	3	0.03 ±0.22	19	0.18 ±1.20	N/A	N/A	22
Sagebrush Lizard (*Sceloporus graciosus*)	0	0	14	0.13 ±1.09	N/A	N/A	14
Lizard subtotals	13	0.13 ±0.45	77	0.71 ±2.01	N/A	N/A	90
Percent of total		14.4		85.6		N/A	1.7
Sharp-tailed Snake (*Contia tenuis*)	0	0	4	0.04 ±0.23	N/A	N/A	4
Western Racer (*Coluber constrictor*)	0	0	1	0.01 ±0.10	N/A	N/A	0
Ringneck Snake (*Diadophis punctatus*)	0	0	7	0.06 ±0.31	N/A	N/A	7
Mountain Kingsnake (*Lampropeltis zonata*)	0	0	1	0.01 0.10	N/A	N/A	1
Terrestrial Garter Snake (*Thamnophis elegans*)	0	0	2	0.02 ±0.19	N/A	N/A	2
Northwestern Garter Snake (*Thamnophis ordinoides*)	1	0.01 ±0.10	4	0.04 ±0.23	N/A	N/A	5
Common Garter Snake (*Thamnophis sirtalis*)	0	0	1	0.01 ±0.10	N/A	N/A	1
Snake subtotals	1	0.01 ±0.10	20	0.19 ±0.66	N/A	N/A	21
Percent of total		4.8		95.2		N/A	0.4
Reptiles and amphibians combined	1642		2308		1422		5372
Percent of total		30.6		43.0		26.4	100

[1] 49 samplings each year.
[2] X=mean per sampling session ± 1 standard deviation.
[3] 54 samplings each year.
[4] 21 samplings in 1984 and 19 in 1985.

or Slender Salamanders compared with TCS (see also Bury and Raphael 1983, Raphael and Rosenberg 1983). In addition, PF captured one Arboreal salamander, a species not captured by other methods. This species reaches the northern extreme of its range near our southernmost pitfall sites. It rarely occurs in mixed coniferous-hardwood forests, so this result should not be interpreted to indicate the PF's unique ability among the three methods to detect this species. The captures of Tailed and Foothill Yellow-Legged Frogs occurred at sites adjacent to streams, indicating that PF effectively samples some species of aquatic frogs if trapping sessions are timed to correspond with periods of overland migration (see also Bury and Corn 1987).

Reptiles

Pitfall trapping captured only 14.4 percent of lizards and 4.8 percent of snakes taken by the two terrestrial methods combined. They captured all but one species of lizard but only a single species of snake taken by TCS (table 1).

Time-Constrained Searches

TCS yielded 24 species, more than either PF or area-constrained aquatic searches (AQS). Only two species-the Yellow-Legged Frog and the Arboreal Salamander-were not detected by this method. TCS also gave the most captures for the study (table 1). Nine species were captured only or primarily by this method (75 percent or more of captures from all sites in both years).

Species-presence records (table 2) ranged from 1 to 7 for the 54 sites in 1984. The range for new species per plot in 1985 was 0-4, and in 1986 it was 0-3. The dramatic increase in the mean number of captures per site in 1986 (table 2) is a

Table 2--Within- and between-year captures and species-presence records for pitfall trapping and time-constrained searches in woodland habitats of northwestern California and Southwestern Oregon. 1984-1986.

	Pitfall grids (49 plots)			Time-constrained searches (54 plots 1984, 1985; 30 plots 1986)		
Sampling session	First 30 nights, Fall 1984	Last 20 nights, Fall 1984	30 nights, Fall 1985	Spring 1984	Spring 1985	Spring 1986
Number of captures	675	414	554	1197	1111	1021
Mean number of captures per plot (±1 S.D.)	13.77 (±18.38)	8.45 (±8.28)	11.31 (±10.51)	22.16 (±15.42)	20.57 (±15.44)	34.03 (±16.36)
Change of mean from previous year (pct.)	--	--	[1]-19.2	--	-7.7	+39.5
Number of new species-presence records	103	30	28	147	62	26
Number of plots with new species-presence records	49	20	20	54	35	22
Percent of plots sampled with new species-presence records	100	40	40	100	65	73
Increase from previous session (pct.)	--	+22.5	+16.8	--	+29.6	+11.0
Mean no. of new species-presence records per plot (+1 S.D.)	2.10 (±1.03)	0.61 (±0.79)	0.57 (±0.89)	2.72 (±1.43)	1.15 (±1.14)	0.87 (±1.04)

[1]Compared with first 30 days of 1984.

result of sampling only the more southern sites. The 15 searches on more northern sites, around Cave Junction, Oregon, yielded markedly fewer individuals per site than the remaining sites in 1984 and 1985, and thus negatively affected the overall mean number of individuals per site for those years.

Comparing the mean numbers of new species present per site and per year (fig. 3) for 1984 and 1985 combined, PF yielded 160 new records or 43.6 percent, and TCS yielded 209 new records or 56.4 percent. In 1984 the two methods were nearly equal at 2.7 new species per site, however in 1985, TCS yielded 62 new records for 69.7 percent while PF produced 27 new records for 30.3 percent. TCS, an active sampling method, is clearly superior, over the long term, for accumulating new species richness information.

Amphibians

TCS was the least effective of the three methods for sampling frogs; however, the primarily terrestrial Pacific Treefrog showed the reverse with 74.2 percent of captures by TCS (table 1). TCS proved highly effective for sampling terrestrial salamanders; 8 of 9 species were collected by this method. TCS is clearly a superior method for sampling Clouded Salamanders and Slender Salamanders, the two species underrepresented in pitfall sampling, and the Olympic Salamander, a species of low vagility that rarely wanders far from the seeps and springs it inhabits.

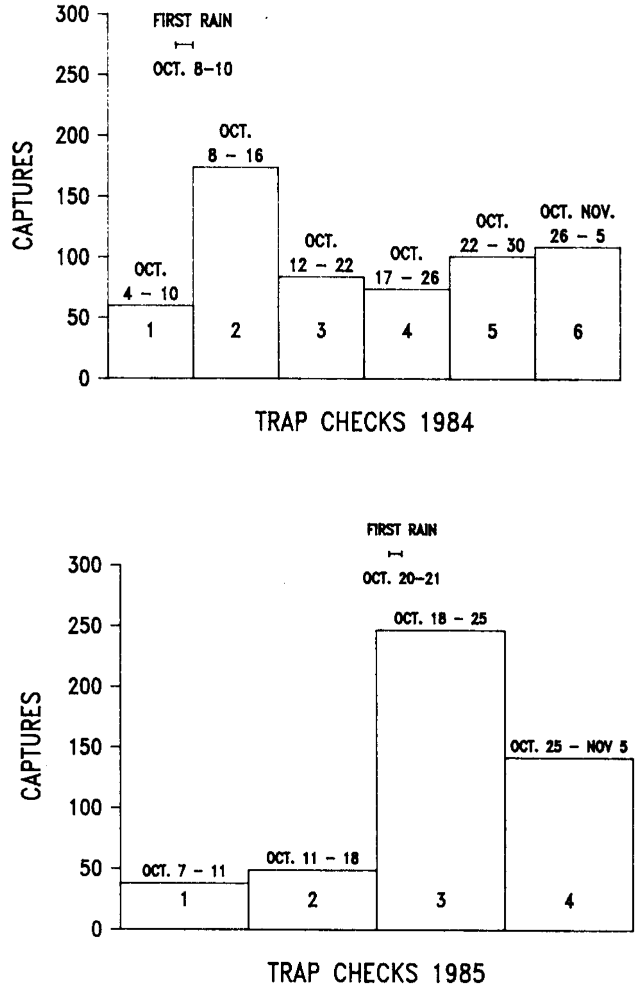

FIGURE 1.--NUMBERS OF HERPETOFAUNA COLLECTED IN PITFALL TRAPS IN WOODLAND HABITATS OF NORTHWESTERN CALIFORNIA AND SOUTHWESTERN OREGON IN 1984 AND 1985.

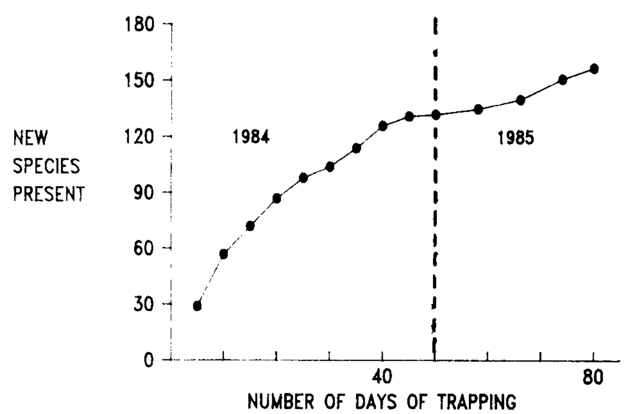

FIGURE 2.--RECORDS OF NEW SPECIES PRESENT, FROM FALL PITFALL TRAPPING AT 49 SITES IN 1984 AND 1985 IN WOODLAND HABITATS OF NORTHWESTERN CALIFORNIA AND SOUTHWESTERN OREGON.

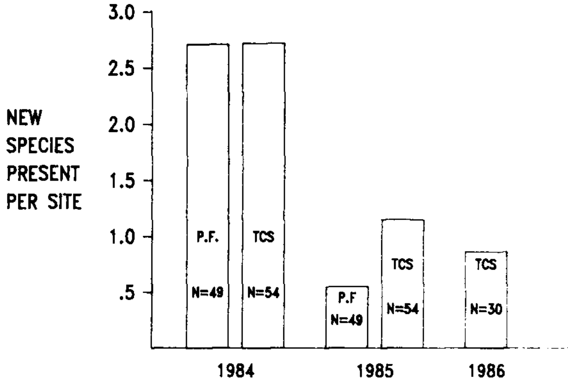

FIGURE 3.--RATES OF NEW SPECIES PRESENT PER SITE FOR PITFALL TRAPPING AND TIME-CONSTRAINED SEARCHES FOR HERPETOFAUNA IN 1984, 1985, AND 1986 IN WOODLAND HABITATS OF NORTHWESTERN CALIFORNIA AND SOUTHWESTERN OREGON.

Reptiles

TCS was the most effective method for detecting the presence of reptiles; 7 of 12 species of reptiles were taken only by this method (table 1). TCS accounted for 86.5 percent of the 111 reptiles collected.

Area-Constrained Aquatic Searches

AQS captured the smallest share of specimens of the three methods (table 1). However, AQS was used at only about a third as many sites as each of the other methods; it actually yielded the highest average number of captures per site (table 3). All captures were amphibians of seven species, two of which the Tailed Frog and the Pacific Giant Salamander were detected primarily by this method (table 1). The majority of captures of these two species were larval animals. AQS accounted for 97.6 percent of Tailed Frogs and 95.3 percent of the Pacific Giant Salamanders.

Because AQS was so time consuming, only half the sites were sampled in each year. Thus I could not analyze AQS data for year-to-year changes.

Cost Analysis of Sampling Methods

TCS was the most cost-effective of the three techniques tested, requiring an intermediate number of personnel, the least amount of tine, and the lowest cost per sampling period, while yielding the highest rate of captures per person-hour of effort and the lowest average cost per capture (table 3). Also, this technique required no site preparation. Sites could be selected and sampled immediately, and sampling was completed in a matter of several hours. Pitfall trapping required a much more extensive

Table 3--Cost-and-yield of methods used to sample herpetofauna in woodland habitats of northwestern California and Southwestern Oregon in 1983 and 1984.

Factor	Pitfall trapping	Time-constrained searches	Area-constrained aquatic searches
Type of data generated	Presence/ absence; relative abundance and biomass of some species sampled; macrohabitat associatiions.	Presence/absence; relative abundance and biomass of all species sampled; macro- and micro-habitat associations.	Presence/absence; relative and absolute abundances' and biomass of all species sampled; macro- and micro-habitat associations; microhabitat preference[1].
Plots sampled each year	49	54	18
Total samples	98	108	36
Species detected	19	24	7
Species detected only or primarily[2] by this method	2	9	2
Total captures	1642 [6](3393)	2308	1422
Mean captures per sample, ±1 S.D. (both years combined)	16.78: [6](34.62: ±19.42 ±28.44)	21.37: ±15.38	35.55: ±22.67
Persons required for one sampling period	1	2	3
Time required for one sampling period (hours)	[3]5	2	[4]6
Person-hours required per sample	[3]5	4	18
Captures per person-hour	3.36 [6](6.92)	5.3	2.02
Cost per sample[5]	$89.96	$27.68	$124.56
Average cost per capture[5]	$5.36 [6](2.60)	$1.30	$3.50

[1] Each study plot was mapped for microhabitat availability as well as searched for microhabitat associations, thus allowing the determination of microhabitat preference.
[2] Method accounts for 75 percent or better of all captures.
[3] Does not include installation time of 3-6 hours for a 36-trap grid; assumes a weekly trap check and a 30-day trapping period.
[4] Based on an average of 2 hours to search a 5-meter reach of second order stream, with 3 reaches searched per stream. Does not include time for scale mapping of reaches needed if microhabitat availability data is desired.
[5] Cost is based on personnel being GS-5 level biotechnicians at $6.92 per hour does not include travel costs; Includes initial set-up cost of $110.72 per plot (16 person-hours) for measuring and marking trap grids and burying traps.
[6] Including small mammals.

site preparation and periodic maintenance along with regular checking during trapping sessions.

Pitfall traps were seemingly the most expensive of the three methods when set-up costs were included in the cost analysis (table 3). Measuring and flagging the trapping grid, and installation of the 36 traps per grid required an average of 16 person-hours; resulting in a set-up cost of $110.72 per grid (based on $6.92/hr per person). This resulted in an average cost per capture of $5,36 for the 1642 reptiles and amphibians collected over the 2 years. However, it is important to bear in mind that this cost considers only the herpetofauna collected. Pitfall traps simultaneously sample small mammals. During the 2 years of this study, the 49 pitfall grids collected 1,751 small mammals representing 17 species. When these data are considered, the average cost per capture, including set-up costs, was $2.60; making PF the second most cost-effective per capture of the three methods (table 3). PF becomes increasingly more cost-effective with repeated grid use.

AQS was the most expensive of the three methods for average cost per capture; it required the most people and the most time per sampling and yielded the lowest rate of capture per person-hour (table 3). As noted above, however, AQS did yield the highest average number of captures per site, illustrating its effectiveness for determining abundance and biomass per unit area. Because of the relative sampling effort per unit area, neither of the other methods can approach the accuracy of AQS for relative density or biomass estimates.

DISCUSSION

Herpetofaunal sampling programs need to be designed with specific information goals in mind, as well as for specific habitats and their associated fauna. For example, data from this, study are being analyzed to elucidate differences in the herpetofaunal community relative to changes in the Douglas-fir forest chronosequence. To accomplish this and corollary research objectives, we used sampling protocols (with some modifications) from a companion study in Oregon and Washington (Bury and Corn, Corn and Bury in prep.). For most monitoring requirements, species richness and relative abundance data are sufficient to establish and follow trends. Since pitfall trapping, time-constrained searches, and area-constrained searches can all yield these data, it is important to consider several interrelated factors in evaluating which method is best for a particular application.

Area-Constrained Searches

In terrestrial woodland habitats, a time-constrained method is more cost-effective than an area-constrained technique (Raphael and others 1982, Campbell and Christman 1982, Bury and Raphael 1983, this paper). Raphael and others (1982) found capture rates in northwestern California to be 10 times as high using a general search technique versus measured litter plots, for the same investment of time. Campbell and Christman (1982) found a time-constrained technique to be twice as effective as an area-constrained method in a Florida study. Nevertheless, area-constrained techniques can be effective for some applications in temperate regions (Bury 1982, 1983). For example, this kind of method proved best suited to my research needs in aquatic habitats. Stream ecosystems present special conditions for sampling. Many amphibians are found only or primarily in streams. Riparian and stream areas, spatially limited by nature, tend to concentrate resident fauna, particularly larval amphibians. These areas provide a proliferation of cover among the boulders, debris, and dense vegetation. Area-constrained sampling proved the best choice of available methods to deal with these conditions. This technique is the most successful and cost-effective where an intensive, meticulous search effort is needed in a restricted area with high densities of animals.

Scale mapping of each stream site during this study also allowed calculation of availability of different habitat types (time and cost were not included in this analysis), allowing determination of the microhabitat preferences of each species. Such techniques can be used only with a terrestrial or aquatic area-constrained search method.

Area-constrained methods appear to be more successfully applied and most cost-effective for comprehensive community sampling in tropical rather than temperate areas, where herpetofaunas are more diverse and abundant (e.g., Scott 1976, 1982; Inger and Colwell 1977; Lieberman-Jaffe 1981).

Pitfall Trapping

Raphael and Barrett (1981) and Raphael and Rosenberg (1983) recommend PF for sampling herpetofauna. Yet, despite its obvious effectiveness, no investigators have found that the entire spectrum of terrestrial herpetofauna can be taken by PF alone. Vogt and Hine (1982) experimented in Wisconsin with a variety of PF arrays combined with drift fences of differing heights and lengths, and with and without accompanying funnel traps. They found combinations of pitfalls, drift fences, and funnel traps to be necessary to capture the entire spectrum of herpetofauna. Bury and Corn (1987), in a similar study in Oregon, were able to achieve a "relatively complete species list" at a given site using pitfall traps with drift fences over 60 days of trapping, but they implied that even with these combinations, probably not all species present were taken. Snakes, and some amphibians, because of their relatively low densities and behavioral traits are not readily captured by PF arrays. This is well illustrated by the differences in our capture rates between TCS and PF for three amphibians: the Clouded Salamander and the Pacific Treefrog--both climbing species that probably catch themselves before falling into traps-and the sedentary Slender Salamander (table 1; Bury and Raphael 1983). Such differences in catchability are important considerations when analyzing relative abundance data.

There are notable differences in several important, interrelated factors, including array design, that merit consideration when employing the PF technique. Timing of the trapping period is the most critical factor and was probably the primary cause for the great differences in mean number of individuals per site and capture rate per trap night among this study and two others that employed PF to sample herpetofauna in the Douglas-fir forests of the Pacific Northwest (table 4). Bury and Raphael (1983) ran their traps continuously for 18 months and thus were able to capture relatively high numbers of both reptiles (lizards) and amphibians. Bury and Corn (1987) timed their trapping effort to coincide with the peak activity periods of reptiles and amphibians. They caught 88.3 percent of the

Table 4--Pitfall trapping (PF) and time-constrained sampling (TCS) of herpetofauna from three studies in the Douglas-fir forests of the Pacific Northwest.

Factor	This study[1] PF[2]	This study[1] TCS	Bury and Corn (1984)[3] PF[2]	Bury and Corn (1984)[3] TCS	Bury and Raphael (1983)[1] PF[2]	Bury and Raphael (1983)[1] TCS
Plots sampled	49	54	30	31	166	84
Traps per plot	36	-	[4]24	-	10	-
Sampling duration per plot	80 Nights	8 Person -hours	180 Nights	[5]8 Person -hours	540 Nights	4 Person -hours
Sampling dates	Oct.-Nov. 1984 (50)	Apr.-May 1984	May-Nov. 1983	Apr.-May 1983	Spring 1981 to	Spring 1982
	Oct.-Nov. 1985 (30)	Apr.-May 1985		Jul.-Aug. 1983	Fall 1982	Fall 1982
Total trap-nights	14,1120	--	129,600	--	896,400	--
Total person-hours of effort	--	432	--	280	--	336
Total species captured	19	24	18	16	[8]13	?
Total individuals captured	1,642	2,308	2,180	382	2,330	1,520
Mean captures per plot (±1 S.D.)	33.51 (±33.56)	42.74	72.66	12.32	14.04	18.10
Capture rate per trap-night (x1000)	11.64	--	16.80	--	2.60	--
Capture rate per person-hour	--	5.34	--	1.36	--	4.04
Total amphibians captured	1,628	2,211	2,060	359	[6]1,350	1,451
Mean captures per plot	33.24	40.94	68.66	12.32	[6]8.1	17.3
Capture rate per trap-night (x1000)	11.54	--	15.90	--	1.50	--
Capture rate per person-hour	--	5.12	--	1.45	--	4.32
Total reptiles captured	14	97	120	8	[7]980	69
Mean captures per plot (±1 S.D.)	0.29 (±0.79)	1.79	4.0	0.26	[7]5.9	0.8
Capture rate per trap-night (x1000)	0.10	--	0.93	--	1.10	--
Capture rate per person-hour	--	0.22	--	0.03	--	0.21

[1]All data from northwestern California 1984 and 1985.
[2]Herpetofauna only, mammals not included.
[3]Wash. and Oreg. data combined; PF data source: Bury and Corn 1987.
[4]Twelve pitfall and twelve funnel traps with drift fences (trap arrays).
[5]An additional 4 person-hours on eight plots only, summer 1983.
[6]Salamanders only reported.
[7]Lizards only reported.
[8]Partial list.

reptiles in the first 90 days (June to August), and 89.6 percent of the amphibians in the second 90 days (September to November). By thus timing their trapping sessions, they were able to capture higher numbers of amphibians per site and per trap night than were Bury and Raphael, with a much smaller investment in time. Their lower numbers of reptiles compared with those of Bury and Raphael were probably due to geography, because they were in the central Oregon Cascades. Reptiles decline in numbers of species and individuals as one goes north along the Pacific Rim (Keister 1971). Nonetheless, timing provided Bury and Corn with comparable means per site and rates per trap night for reptiles.

I timed PF to coincide with the peak activity period of amphibians only (fall). Hence, the low capture rate for lizards compares with that by Bury and Raphael (1983) in the same region. More spring trapping data from northwestern California, preferably with funnel traps (Raphael and Marcot 1986), are needed to evaluate the effectiveness of capturing snakes by passive trapping means in these habitats. Bury and Corn (1984) reported that three species of frogs accounted for 42.0 percent of their total pitfall catch of amphibians; frogs accounted for only 7.9 percent of my PF catch (table 1). The relative difference in frog abundance between the two areas of study (as indicated by sampling methods other than PF) could alone account for most of the relative difference in means per site and capture rates per trap night for amphibians between these studies (table 4). The data reported here show a marked drop in total numbers of individuals captured between 30-day trapping periods in fall 1984 and 1985 (table 2). While the decline may indicate natural population fluctuations or depletion from the first year's sampling, it probably stems in part from the arrival of the fall rains, the advent of which triggers the emergence of many amphibians (see Porter 1972:280). In 1984, the first heavy rains came during the first week of the trapping session, whereas in 1985 they did not begin until the 21st night of trapping (fig. 1). This difference indicates that weather may be the primary factor influencing herpetofaunal activity. Vogt and Hine (1982) also found trapping success to be markedly influenced by weather, and secondarily by season.

A second aspect of timing involves the question of duration versus frequency. Species richness data from the last 20 days of the 50-day trap session in 1984 (table 2) suggested that a longer session in a single year may be a better strategy than shorter sessions in successive years. However, the continued accumulation of new species richness data from PF and TCS (fig. 3) clearly indicate the importance of annual repetition of sampling to achieve more complete species inventories.

Bury and Corn (1984, 1987) used the most efficient array combination (pitfall arrays with drift fences) of the three studies (table 4). Our study used a large number of traps per grid (36) to compensate for not using drift fences or funnel traps. Except for frogs, our pitfall grid design (36 traps) yielded mean numbers of individuals per site and capture rates per trap night comparable to the pitfall arrays with fences (Bury and Corn 1984, 1987). We had four times the numbers of amphibians per site as Bury and Raphael (1983), who used the fewest traps per site (10), and no drift fences. Despite the continuous run of 18 months, Bury and Raphael's trapping design was the most inefficient trapping design of the three studies (table 4).

Time-Constrained Searches

My data indicate that PF does not record as many species of herpetofauna as does the TCS method (table 1). Because PF, or PF with drift fences, does not always capture all species of herpetofauna present in a study area, a complementary or alternative method may be desired. Bury and Raphael (1983) recommend a combination of time-constrained searches and pitfall trapping "...for one of the best inventories of terrestrial herpetofaunas." The relatively high capture rates per person-hour of sampling effort (table 4) for my TCS study and that of Bury and Raphael (1983) compared with Bury and Corn (1984), are probably an artifact of the previously mentioned geographic gradient. The advantages of TCS over PF are not as marked in northern as in southern Pacific areas for reptiles and amphibians. The superiority of TCS for sampling reptiles is not as obvious because reptiles are less prominent in northern herpetofaunal communities. Amphibians in the north are more abundant and have more protracted activity periods in the cooler and moister habitats so that PF can adequately sample them. Bury and Corn's (1984) work suggests that PF is the best single choice in the forested areas of Washington and Oregon. TCS is clearly the best method for denoting occurrence of the rarer species (snakes) and for species that are not readily captured by pitfalls (e.g., Clouded Salamander), again because they can be sought out in their favored microhabitat. Furthermore, our study indicated that TCS was more cost-effective than PF, yielding higher captures both per site and per person-hour of sampling effort (table 3).

Aquatic habitats are critical to many species of amphibians, many of which require permanent water during egg and larval stages. Any comprehensive monitoring program for herpetofauna should include surveying of aquatic and riparian habitat. No effort was made to evaluate a time-constrained method in second- and third-order stream habitats. However, I did use a separate TCS method at terrestrial sites with seeps, springs, and first-order streams to sample for Olympic Salamanders. The TCS method is readily adaptable to riparian and aquatic habitats and would be the most cost-effective for meeting the monitoring objectives of determining species richness and relative abundance.

Integrating Methods

My data favor the TCS method over other methods based on comprehensive, cost-effective monitoring of herpetofauna (tables 1 and 3). However, counterbalancing factors such as long-term cost can make PF attractive for many applications. PF grids are initially more expensive than TCS but relatively cheap over the long term, because the major expenses are materials and installation (Raphael and Rosenberg 1983). Thereafter, travel and checking time are the major costs. Pitfalls can then be used for continuous or periodic monitoring indefinitely, with minimal resources and no impact on the habitat (unlike TCS and ACS which can be locally disruptive). However, populations may be locally impacted if mortality occurs, rendering subsequent capture rates biased downward. Another significant advantage of pitfalls is that they simultaneously monitor the small manorial community. Raphael and Rosenberg (1983) point out that the most cost-effective use of PF can be in conjunction with other vertebrate sampling techniques, such as bird censuses, that can be used during the same site visit. Ultimately, the best choice of combined sampling methods depends on the information objectives and site peculiarities of a given situation. The variables to consider and the options available are outlined below.

The relatively high standard deviation values reported for these methods (tables 1 and 2), are a reflection of three interacting phenomena: (1) the rareness of many species; (2) the patchiness of their distributions in forest habitats; and (3) the high variability among study sites. Sites were selected in order to sample the entire age and moisture spectrum present in the Klamath-Siskiyou Mountain Douglas-fir forest. AQS showed the lowest standard deviations per taxa (table 1), probably because only stream habitats were sampled with this method, and these are consistently more uniform than terrestrial habitats. Of the two terrestrial sampling methods, TCS showed the least variability (table 2), probably because this active sampling technique permits the workers to sample the more favored habitat patches in greater proportion to their actual occurrence in the forest during the timed period.

DESIGNING A HERPETOFAUNAL MONITORING PROGRAM

The following outline is a guide for resource managers or investigators who need to collect information on the distribution and abundance of reptiles and amphibians. The variety of herpetofaunal life forms and natural history, and the differences in their abundance and observability, create special problems for designing a comprehensive monitoring program. A suggested approach should address the following:

I. What kind of information is needed about the target species?
   A. Presence/absence or species-richness data
      1. Requires minimum of annual sampling, timed to coincide with the period of greatest visibility or accessibility of subject species. (For some species, such times may correspond to periods of migration when they may not be in optimum habitat.)
      2. Initial and repeat sampling should occur in characterized areas. Application of data to a wider area should be done only with reservation and with particular attention to similarities of substrate, vegetation, elevation,

latitude, and similarities of microclimate.

B. Relative abundance data
   1. All questions of relative abundance require equal sampling effort at each site and each year to assure accuracy and reliability of data.
   2. Types of relative abundance data:
      a. The same species from year to year at site A;
      b. Different species in a given year at site A;
      c. The same species in different habitats (site A vs. site B) in a given year, or between years. (Note: differences in detectability among species, and for a given species by different sampling methods or in different habitat types, sampling designs for the above questions may not yield comparable data.)
   3. Differences in climate from year to year can significantly affect sampling results and may obscure actual relative abundance values. Yearly or seasonal sampling periods should not be by the calendar, but by the onset of spring or fall rains (optimum search time for amphibians), or after the spring rains (optimum search time for reptiles); longer or more frequent sampling periods can also help alleviate this problem.

C. Absolute abundance data (or the closest approximation thereof)
   1. Obtainable only by intensive, area-constrained searches; generally not cost-effective for long-term monitoring of herpetofaunal communities. These methods do, however, produce the only density estimates and therefore can provide the best documentation of change over time.
   2. Most likely application for resource management agencies would be in cases of rare species with limited or patchy distributions.

D. Macro- and microhabitat associations and/or microhabitat preferences
   1. All sampling methods yield macrohabitat data
   2. Microhabitat associations can be obtained from time- and area-constrained methods (Raphael, this symposium).
   3. Microhabitat preferences require area-constrained techniques with scale habitat mapping to quantify available vs. used habitat.

E. Demographic data. These data require area-constrained and mark-release-recapture techniques for the recognition of individuals (Ferner 1979).

II. What species are likely to be encountered and what are their life histories?

A. Seasonal limits of surface activities (e.g., rainy or dry season)

B. Temporal patterns of activities (nocturnal, diurnal, or crepuscular)

C. Basic macrohabitat affinities (terrestrial, aquatic, fossorial, arboreal, or combinations of these).

III. What sampling and monitoring methods are available?

A. Pitfall trapping (and transect census techniques)
   1. Advantages
      a. Yield data on species richness, relative abundance, and microhabitat
      b. Do not require highly trained personnel if specimens are collected for later identification
      c. Most cost-effective for frequent sampling-e.g., continuously, seasonally, or monthly
      d. Least effort required once trap arrays are in place
      e. Animals can be marked and released alive for demographic data if traps are checked frequently (daily)
      f. Will sample small mammals simultaneously
      g. Relatively high sample sizes if timed correctly.
   2. Disadvantages
      a. Unequal catchability-those species with low vagility or with good climbing abilities may not be captured in proportion to other species in an area.
      b. High mortality of captures if the traps not checked frequently
      c. No data possible on microhabitat associations.

B. Time-constrained methods
   1. Advantages
      a. Yield data on species richness, relative abundance, macro- and microhabitat association, and demographics (via mark and release)
      b. Workers can focus on preferred microhabitats, promoting higher sample sizes per unit time than with passive methods
      c. Possible with trained personnel to do minimal destructive sampling of habitat.
   2. Disadvantages
      a. Hard to control for equal sampling effort if personnel change during monitoring program
      b. Important to train personnel to alleviate observer bias in searching; important that all microhabitat be searched, not just where "best" species are found
      c. Untrained personnel can destroy important cover habitat, affecting subsequent sampling.

C. Area-constrained methods
   1. Advantages
      a. Yield data on species richness, relative and absolute abundance, biomass, microhabitat association, habitat preference, and demographics
   2. Disadvantages
      b. Labor intensive and time-consuming, thus the most expensive method

IV. What resources are available and how do they tie in with the resource requirements for each of the monitoring methods?
   A. Equipment
   B. Personnel (and training required to identify species and know their habitat associations to effectively use any of these sampling techniques)
   C. Time (per year or year to near, including travel time)
   D. Actual cost.

ACKNOWLEDGMENTS

I thank the members of the field crews of the Pacific Southwest Forest and Range Experiment Station's, Timber/Wildlife Research Unit for their help in collecting the data. Megan Haney and Amy Lind deserve special thanks for their help with data analysis. I thank Peter W. Paton, R. Bruce Bury, Paul S. Corn, Martin G. Raphael, Jared Verner, Harold Basey , Amy J. Lind, and Megan A. Haney for their comments on earlier drafts of the manuscript.

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Preliminary Results From a System for Monitoring Trends in Bird Populations in Oak-Pine Woodlands[1]

Jared Verner[2]

Abstract: Three observers independently sampled the bird assemblage at the San Joaquin Experimental Range, in central California, by completing 5-min point counts at 210 counting stations during April 1985. Either total counts or frequencies, or both, could be used for monitoring trends in relative abundance of birds, but density estimates are not suitable because only a small percentage of bird species are detected often enough to permit such estimates. Results indicate that difference between observers is the major source of variation in counts; probably at least three observers should be used to monitor trends in bird populations.

The National Forest Management Act of 1976 (U.S.C. 1600-1614) mandates the monitoring of wildlife populations on all National Forest lands. Some guidelines are given in regulations pursuant to the Act (36 CFR 219), but specific methods are not covered. Because cost analyses show that some methods now used to measure animal abundance would be prohibitively expensive in a large-scale monitoring effort (Verner 1983), research is needed to identify suitable methods that are more cost effective. Much interest in the development of such methods for wildlife populations in hardwood habitats has been expressed, not only in the Forest Service, but also at the State level in California (Graves 1985, Mayer 1985).

This paper reports certain results of the first year's sampling of a test system of point counts installed in oak-pine woodlands at the San Joaquin Experimental Range, Madera County, in central California, to monitor yearly variations in bird populations. The system is applicable to areas of medium to large size (>1800 ha); smaller areas would not accommodate the number of counting stations needed at a minimum distance of 300 m between stations. The primary objectives of this study were to evaluate total counts, frequencies, and density estimates as measures of the relative abundance of birds, specifically for use in monitoring population trends over time; and to characterize observer variability for each of these measures.

STUDY AREA

The San Joaquin Experimental Range (SJER) is an area of 1875 ha, ranging in elevation from 215 to 520 m, in the western foothills of the Sierra Nevada of California. The climate is characterized by cool, wet winters and hot, dry summers. Annual precipitation averages 48.6 cm (43-yr mean, 1935-77), most of which is rain from November through March. Vegetation over most of SJER is characterized by an overstory of blue oak (*Quercus douglasii*), digger pine (*Pinus sabiniana*), and interior live oak (*Q. wislizenii*). An understory of scattered shrubs includes mainly buck brush (*Ceanothus cuneatus*), chaparral whitethorn (*C. leucodermis*), redberry (*Rhamnus crocea*), and Mariposa manzanita (*Arctostaphylos mariposa*). In a few smaller patches, the overstory is primarily blue oak, and a shrub understory is meagre or missing. Some areas of typical annual grasslands extend throughout the remainder of SJER where the overstory and understory are not dense enough to shade them out or are lacking altogether.

METHODS

Seven lines with 30 counting stations each were established primarily in oak-pine habitat throughout SJER, with the aid of aerial photos and topographic maps (scale = 13,500:1; contour interval = 38 m). Counting stations were at least 200 m apart along the same line and between the separate lines. (Closer spacing than is ideal for independent samples was used here to allow six counts per hour.) All counting stations were clearly identified by placement of large cattle ear tags wired to fences, trees, shrubs, and occasionally to steel fence posts set in open areas specifically for that purpose. Numerous additional tags placed between stations along the line gave directions for continuing along the line; a "tour guide" was prepared to describe in detail the location of each tag, what it was wired to, and the distance and direction to the next tag along the line. With this system, observers unfamiliar with the lines were able to follow them quickly and accurately.

Recording of birds along any line began at the first station on the line at 10 min after official sunrise. The counting period was 5 min, after which the observer moved quickly to the next station and began counting at exactly 10 min after counting began at the first station. By

[1]Presented at the Symposium on Multiple-Use Management of California's Hardwood Resources, November 12-14, 1986, San Luis Obispo, California.

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adhering to this schedule, an observer recorded birds at 6 stations per hour, so all 30 stations on a line could be sampled within 5 hr, and the entire system could be sampled by one observer in seven mornings. Counts were not done during rainy mornings, and counts done during days when wind consistently exceeded 20 mph (by Beaufort scale) were repeated the following count day. Windy day counts were not included in the present analysis.

Results reported here were taken from April 22 to May 1, 1985, by three observers randomly assigned to lines in such a way that none sampled the same line on the same day and all sampled all seven lines. Observers were carefully selected to be expert birders and especially to be expert in the identification of birds at SJER by sight and sound. At each station, they recorded the date, time, wind velocity, percent cloud cover, rain activity, and temperature. For each bird detected, they recorded the species, cue (visual, song, call, or other sound) first detected, distance (in meters) from the counting point, age (adult or juvenile), and whether the bird had probably been detected from a previous point that morning. Each observer's hearing was tested within a week after the field work was finished.

Statistical tests are identified, as appropriate, in the results section; statistical significance has been arbitrarily set at a probability level of 0.05.

RESULTS

Community Measures

Total Count

Collectively the three observers recorded 7380 individual birds: 2470 for Observer 1, 2995 for Observer 2, and 1915 for Observer 3 (table 1). Total counts of all birds on the seven lines of counting stations differed significantly (paired *t* tests) in all pairwise comparisons between observers (table 2). Variability in total counts of individual species among the three observers was surprisingly large (table 1). Coefficients of variation (CV) ranged from 6.9 to 173.2 percent, with a mean *of 77.7* percent (*n* = 79). Frequency data were no better, with a mean CV of 74.7 percent and a range of 0 to 173.2 percent (see table 1).

Observer differences contributed more to this than did differences among counting stations. When results were totaled separately for each of the seven lines of 30 counting stations (table 2), the mean CV of total counts for observers by line was 23.7 percent (range = 18.7 to 33.6 percent), but that for lines by observer was only 14.2 percent (range = 12.7 to 15.8 percent). These CVs were less than those for total counts by species separately because they consisted of much larger samples--pooled results for all species at each of 30 counting stations in each sample.

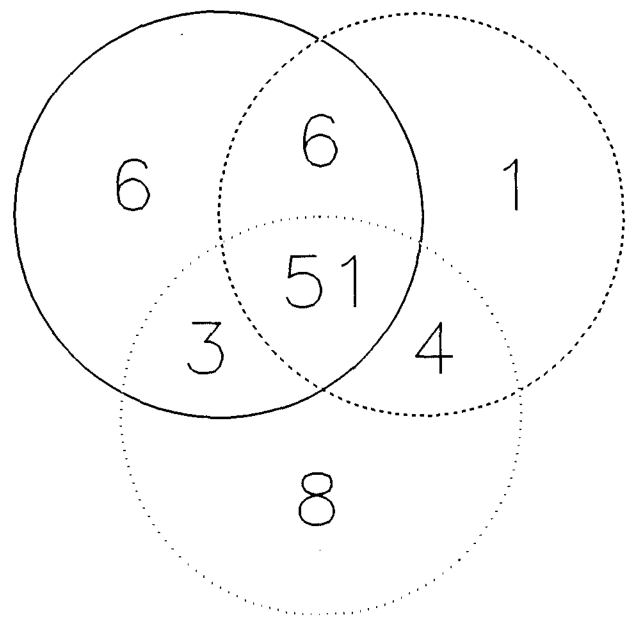

Figure 1.--Venn diagram showing the numbers of species detected only by Observers 1 (solid circle), 2 (circle with heavy dots), and 3 (circle with light dots); by the three possible pairs of observers; and by all three observers combined.

Species Richness

The three observers combined recorded 79 species; 51 were seen by all observers, 13 were seen by only two, and 15 were seen by only one (fig. 1). Most of the species seen by only one or two observers were uncommon, with only 3 or fewer being detected by any observer. Some striking exceptions occurred, however. For example, Observers 2 and 3 recorded 9 and 8 American Robins, respectively, and 10 and 7 Golden-crowned Sparrows, but Observer 1 recorded none of either species. Observer 3 recorded 8 Nashville Warblers, Observer 1 recorded 2, but Observer 2 recorded none. Other disquieting variation was found in the data. For example, among the common and easily detected species, Observer 2 recorded more California Quail than the other two observers combined, and Observer 1 recorded more than twice the number of Acorn Woodpeckers recorded by Observer 3.

Although Observers 1 and 3 each recorded 66 species, Observer 3 detected significantly fewer species per line than Observer 1 (*t* = 2.66, *n* = 7) (table 2). On the other hand, Observer 2 did not differ significantly from either of the other observers in the mean number of species detected per line, although detecting only 62 species over the whole set of 210 counting stations. Finally, bootstrap simulation of species-accumulation curves showed no significant differences in any pairwise comparison of observers when results were taken over all 210 counting stations (fig. 2).

TABLE 1. Total counts and frequencies (number of stations where detected/total number of stations sampled, with frequency <0.0050 denoted as +) of all species recorded by each observer during the 1985 sample of the monitoring system at the San Joaquin Experimental Range.

	Total counts					Frequencies			
Species	Obs. 1	Obs. 2	Obs. 3	Mean	2SE	Obs. 1	Obs. 2	Obs. 3	Mean
Wood Duck (*Aix sponsa*)	1	7	0	2.7	4.3	+	0.02	0	0.01
Mallard (*Anas platyrhynchos*)	4	0	1	1.7	2.4	0.01	0	+	+
Turkey Vulture (*Cathartes aura*)	48	62	43	51.0	11.2	0.15	0.18	0.11	0.15
Cooper's Hawk (*Accipiter Cooperii*)	1	5	0	2.0	3.0	+	0.02	0	0.01
Red-tailed Hawk (*Buteo jamaicensis*)	49	51	37	45.7	8.6	0.20	0.21	0.13	0.18
Golden Eagle (*Aquila chrysaetos*)	0	1	3	1.3	1.7	0	+	0.01	+
American Kestrel (*Falco sparverius*)	5	5	3	4.3	1.3	0.02	0.02	0.01	0.02
California Quail (*Callipepla californica*)	72	135	46	84.3	51.8	0.28	0.53	0.20	0.33
Killdeer (*Charadrius vociferus*)	17	2	4	7.7	9.2	0.06	0.01	0.02	0.03
Mourning Dove (*Zenaida macroura*)	183	186	103	157.3	53.3	0.50	0.64	0.39	0.51
Greater Roadrunner (*Geococcyx californianus*)	5	0	9	4.7	5.1	0.02	0	0.04	0.02
Great Horned Owl (*Bubo virginianus*)	2	1	1	1.3	0.7	+	+	+	+
Northern Pygmy-Owl (*Glaucidium gnoma*)	1	0	0	0.3	0.7	+	0	0	+
Vaux's Swift (*Chaetura vauxi*)	0	0	1	0.3	0.7	0	0	+	+
Anna's Hummingbird (*Calypte anna*)	30	22	22	24.7	5.2	0.14	0.10	0.10	0.11
Unidentified hummingbird	0	7	0	2.3	4.6	0	0.03	0	0.01
Acorn Woodpecker (*Melanerpes formicivorus*)	311	294	151	252.0	99.4	0.72	0.82	0.59	0.71
Nuttall's Woodpecker (*Picoides nuttallii*)	3	13	14	10.0	6.9	0.01	0.06	0.07	0.05
Hairy Woodpecker (*Picoides villosus*)	0	0	2	0.7	1.3	0	0	+	+
Northern Flicker (*Colaptes auratus*)	2	19	12	11.0	9.7	0.01	0.08	0.06	0.05
Dusky Flycatcher (*Empidonax oberholseri*)	3	1	1	1.7	1.3	0.01	+	+	0.01
Gray Flycatcher (*Empidonax wrightii*)	0	1	3	1.3	1.7	0	+	0.01	0.01
Unidentified *Empidonax* Flycatcher	13	12	7	10.7	3.6	0.06	0.06	0.03	0.05
Black Phoebe (*Sayornis nigricans*)	2	1	1	1.3	0.7	0.01	+	+	0.01
Ash-throated Flycatcher (*Myiarchus cinerascens*)	167	217	119	167.7	55.4	0.58	0.74	0.49	0.60
Western Kingbird (*Tyrannus verticalis*)	57	43	34	44.7	13.1	0.15	0.15	0.14	0.15
Tree Swallow (*Tachycineta, bicolor*)	0	0	2	0.7	1.3	0	0	+	+
Violet-green Swallow (*Tachycineta thalassina*)	135	189	90	138.0	56.1	0.31	0.42	0.25	0.33

TABLE 1 cont'd

Species	Total counts					Frequencies			
	Obs. 1	Obs. 2	Obs. 3	Mean	2SE	Obs. 1	Obs. 2	Obs. 3	Mean
Barn Swallow (Hirundo rustica)	2	0	0	0.7	1.3	0.01	0	0	+
Scrub Jay (Aphelocoma coerulescens)	118	164	96	126.0	39.3	0.45	0.53	0.40	0.46
Common Raven (Corvus corax)	18	18	15	17.0	2.0	0.06	0.08	0.07	0.07
Plain Titmouse (parus inornatus)	226	296	103	208.3	110.6	0.71	0.78	0.46	0.65
Bushtit (psaltriparus minimus)	24 43	35	50	36.3	14.8	0.05	0.13	0.13	0.11
White-breasted Nuthatch (Sitta carolinensis)		95	58	65.3	30.3	0.19	0.39	0.25	0.28
Rock Wren (Salpinctes obsoletus)	2	6	10	6.0	4.5	0.01	0.02	0.04	0.02
Canyon Wren (Catherpes mexicanus)	16	18	16	16.7	1.3	0.07	0.09	0.08	0.08
Bewick's Wren (Thryomanes bewickii)	77	127	85	96.7	30.0	0.31	0.46	0.40	0.39
House Wren (Troglodytes aedon)	146	108	106	120.0	25.5	0.51	0.40	0.47	0.46
Ruby-crowned Kinglet (Regulus calendula)	0	0	5	1.7	3.3	0	0	0.02	0.01
Blue-gray Gnatcatcher (Polioptila caerulea)	9	10	11	10.0	1.1	0.04	0.05	0.05	0.05
Western Bluebird (Sialia mexicana)	43	51	27	40.3	13.8	0.12	0.20	0.10	0.14
Townsend’s Solitaire (Myadestes townsendi)	1	0	0	0.3	0.7	+	0	0	+
American Robin (Turdus migratorius)	0	9	8	5.7	5.6	0	0.03	0.03	0.02
Wrentit (Chamaes fasciata)	0	0	1	0.3	0.7	0	0	+	+
Phainopepla (Phainonepla nitens)	4	3	1	2.7	1.7	0.01	0.01	+	0.01
European Starling (Sturnus vulgaris)	114	94	85	97.7	16.8	0.33	0.28	0.29	0.30
Solitary Vireo (Vireo solitarius)	6	3	13	7.3	5.8	0.02	0.01	0.06	0.03
Hutton's Vireo (Vireo huttoni)	9	19	15	14.3	5.7	0.03	0.08	0.07	0.06
Warbling Vireo (Vireo gilvus)	5	10	23	12.7	10.5	0.02	0.04	0.10	0.05
Orange-crowned Warbler (Vermivora celata)	4	9	23	12.0	11.2	0.02	0.04	0.11	0.06
Nashville Warbler (Vermivora ruficapilla)	2	0	8	3.3	4.7	0.01	0	0.04	0.02
Yellow-rumped Warbler (Dendroica coronata)	10	23	22	18.3	8.2	0.04	0.10	0.10	0.08
Black-throated Gray Warbler (Dendroica nigrescens)	4	3	6	4.3	1.7	0.01	0.01	0.03	0.02
Townsend's Warbler (Dendroica townsendi)	2	2	1	1.7	0.7	0.01	0.01	+	0.01
Hermit Warbler (Dendroica occidentalis)	3	2	10	5.0	4.9	0.01	0.01	0.05	0.02
MacGillivray's Warbler (Oporornis tolmiei)	1	0	0	0.3	0.7	+	0	0	+
Wilson's Warbler (Wilsonia pusilla)	23	13	29	21.7	9.1	0.08	0.06	0.13	0.09

TABLE 1 cont'd

Species	Total counts Obs. 1	Obs. 2	Obs. 3	Mean	2SE	Frequencies Obs. 1	Obs. 2	Obs. 3	Mean
Western Tanager (Piranga ludoviciana)	2	2	0	1.3	1.3	+	0.01	0	+
Black-headed Grosbeak (Pheucticus melanocephalus)	10	17	24	17.0	7.9	0.05	0.08	0.11	0.08
Lazuli Bunting (Passerina amoena)	8	4	0	4.0	4.5	0.01	0.01	0	0.01
Rufous-sided Towhee (Pipilo erythrophthalmus)	0	0	3	1.0	2.0	0	0	0.01	+
Brown Towhee (Pipilo fuscus)	59	92	79	76.7	18.8	0.25	0.35	0.37	0.32
Rufous-crowned Sparrow (Aimophila ruficeps)	0	0	2	0.7	1.3	0	0	0.01	+
Chipping Sparrow (Spizella passerina)	9	27	14	16.7	10.5	0.04	0.12	0.07	0.07
Lark Sparrow (Chondestes grammacus)	26	27	19	24.0	4.9	0.10	0.12	0.08	0.10
Lincoln's Sparrow (Melospiza lincolnii)	0	0	2	0.7	1.3	0	0	0.01	+
Golden-crowned Sparrow (Zonotrichia atricapilla)	0	10	7	5.1	5.8	0	0.04	0.03	0.02
White-crowned Sparrow (Zonotrichia leucophrys)	30	15	18	21.0	9.0	0.05	0.05	0.04	0.05
Dark-eyed Junco (Junco hyemalis)	1	4	0	1.7	2.4	+	0.01	0	0.01
Red-winged Blackbird (Agelaius phoeniceus)	17	24	5	15.3	10.9	0.04	0.06	0.01	0.04
Western Meadowlark (Sturnella neglecta)	35	35	31	33.7	2.6	0.15	0.13	0.13	0.14
Brewer's Blackbird (Euphagus cyanocephalus)	10	14	3	9.0	6.3	0.01	0.04	0.01	0.02
Brown-headed Cowbird (Molothrus ater)	75	98	59	77.3	22.2	0.28	0.35	0.20	0.28
Northern Oriole (Icterus galbula)	97	111	38	82.0	43.9	0.35	0.38	0.15	0.29
House Finch (Carpodacus mexicanus)	8	21	25	18.0	10.1	0.03	0.07	0.12	0.07
Lesser Goldfinch (Carduelis psaltria)	49	101	50	66.7	33.7	0.15	0.34	0.20	0.23
Lawrence's Goldfinch (Carduelis. lawrencei)	3	1	0	1.3	1.7	0.01	+	0	+
American Goldfinch (Carduelis tristis)	3	0	0	1.0	2.0	+	0	0	+
House Sparrow (Passer domesticus)	4	0	0	1.3	2.6	0.02	0	0	0.01
TOTAL SPECIES	66	62	66						
TOTAL INDIVIDUALS	2470	2995	1915						

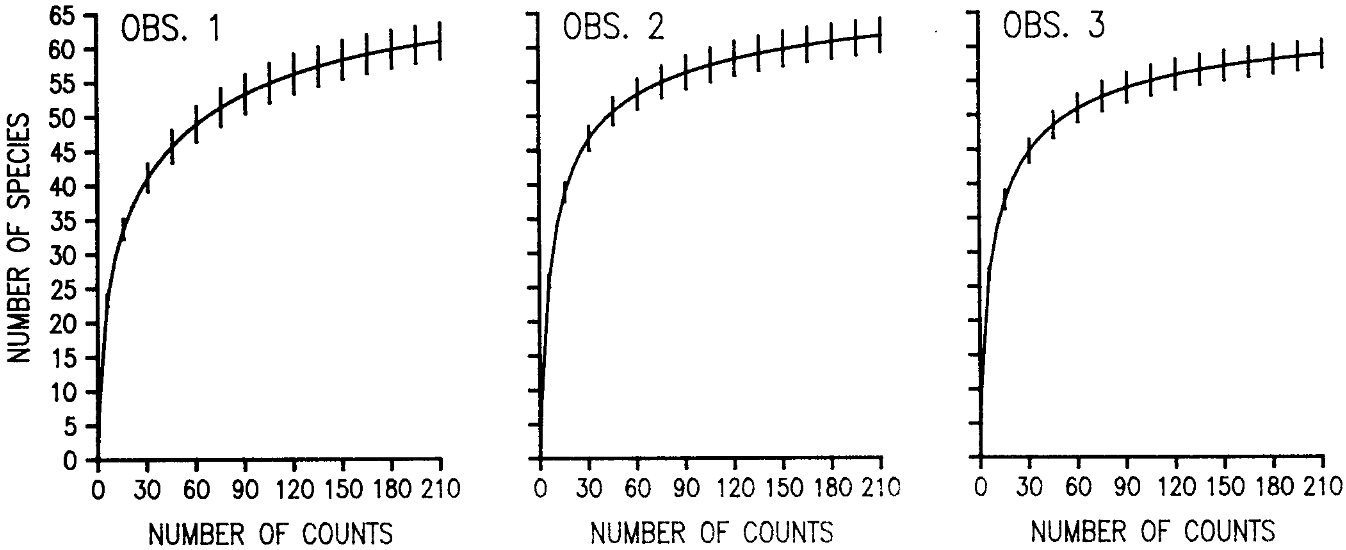

Figure 2.--Bootstrap simulations of species accumulation curves, with confidence intervals shown for each additional 15 counts.

In contrast to results for total counts, observer differences in the number of species detected were less variable than the differences in species counts among the lines. The mean CV of total species for observers by line was 9.4 percent (range = 3.9 to 16.8 percent), and that for lines by observer was 38.3 percent (range = 33.6 to 39.5 percent) (table 2).

Species Measures

Density Estimates

Densities of the most commonly detected species were estimated using the exponential polynomial estimator of program TRANSECT (Laake and others 1979). Judging by a recently completed analysis of data from SJER (Verner and Ritter 1986), I consider 80 records of a given species in a given sample to be the minimum needed for estimating density by transects or point counts. Only seven species satisfied this criterion for all observers in this study (table 3).

Density estimates of the same species differed markedly among observers in most cases (table 3), with the highest estimate exceeding the lowest from 37.7 percent (Acorn Woodpecker) to 201.1 percent (Plain Titmouse). The mean difference across all seven species was 91.8 percent. Pooling data sets between pairs of observers improved this variability markedly. For all species, the percentage difference between the highest and lowest density estimate was reduced, with a mean difference of 36.7 percent (range = 12.2 to 71.6 percent). The overall improvement was significant (t = 3.26; 0.02>P>0.01; n = 7).

Observer 1 had the highest density estimate for most species, with a mean rank of 1.3 (1 = best score possible), and Observer 2 had the lowest estimate for five of the seven species, with a mean rank of 2.7 (3 = worst score possible). In the data sets pooled between pairs of observers, Observers 1+3 had a mean rank of 1.4 and Observers 2+3 had a mean rank of 2.6.

Rank-Order of Abundance

If different observers and different methods accurately measure the relative abundance of bird species, all should rank them in the same order of abundance from most to least common. I tested this for all pairwise comparisons of total counts and frequencies for all observers (table 1), using both Spearman's rho and Kendall's tau. All correlations were significant at the 0.0001 level, those for Spearman's rho (r_s) ranging from 0.82 to 0.99, and those for Kendal's tau ranging from 0.66 to 0.97. At a coarse scale of ranking all species (n = 79) in order of abundance from rare to abundant, all observers performed similarly and the total counts and frequencies of each species gave equivalent rankings.

A similar analysis, using only those species for which density could be estimated, showed that (1) 19 of 28 comparisons among total counts and frequencies were significant at the 0.05 level (r_s >0.713) and 15 of those were significant at the 0.01 level (r_s >0.892)--the lowest r_s was 0.559; (2) no comparison of a count or frequency score with the corresponding density estimate was statistically significant; in fact the highest

TABLE 2. Numbers of species and individuals detected by each observer and all observers combined on each line of 30 counting stations.

	Species detected[1]							Individuals detected						
Line	Obs. 1	Obs. 2	Obs. 3	Total	Mean	SD	%CV	Obs. 1	Obs. 2	Obs. 3	Total	Mean	SD	%CV
A	32	40	45	50	39.0	6.6	16.8	319	424	274	1017	339.0	77.0	22.7
B	36	39	40	54	38.3	2.1	5.4	373	397	274	1044	348.0	65.2	18.7
C	38	47	42	56	42.3	4.5	10.7	356	421	279	1054	352.0	71.1	20.2
D	37	48	47	60	44.0	6.1	13.8	340	435	270	1045	348.3	117.1	33.6
E	42	39	39	53	40.0	1.7	4.3	382	417	271	1070	356.7	76.2	21.4
F	45	42	45	61	44.0	1.7	3.9	380	497	282	1159	386.3	107.6	27.9
G	37	38	45	53	40.0	4.4	10.9	320	404	265	989	329.7	70.0	21.2
Total	66	62	66	79				2470	2995	1915	7380			
Mean	38.1	41.9	43.3	55.3				352.9	427.9	273.6	1054.0			
SD	15.1	15.9	16.2	18.6				49.4	54.5	43.3	85.7			
%CV	39.5	38.0	37.3	33.6				14.0	12.7	15.8	8.1			

[1]Totals for species represent the cumulative numbers of different species detected, not simply the sums of numbers in the respective columns or rows.

r_s in 32 comparisons was 0.429; and (3) 18 of 21 correlations between density estimates of different observers singly or pooled were significant at the 0.05 level, and 10 of those were significant at the 0.01 level.

Although no biological significance can be inferred from values of the correlation coefficients in Spearman's or Kendall's tests (other than the fact that correlations may be significantly different from zero), values in this study suggest that pooling data sets of at least two observers may give more stable estimates of density. The density estimates from data sets pooled for pairs of observers resulted in correlations all significant at the 0.01 level (r_s = 0.964, 0.929, and 0.893), but those comparing density estimates between data sets of single observers were significant only at the 0.05 level or not at all (r_s = 0.857, 0.786, and 0.643).

DISCUSSION

These preliminary results have profound significance for the design of a reliable monitoring system. Variability attributable to counting stations can be eliminated in a monitoring system by using the same counting stations every time a sample is taken. That attributable to observer variability could be similarly controlled if it were possible to use the same observers, year after year, during the life of the monitoring program. Because this is unlikely to be feasible in the vast majority of cases, however, the next best alternative would be to increase the number of observers. The reduction in CV gained by using more observers can be estimated from the formula

$$CV = \frac{(Var/n)^{0.5}}{x}$$

where Var = the variance of a given sample,
n = the number of observers to be used,
x = the sample mean.

Based on the sample obtained in 1985, using two observers would reduce CV by about 29 percent, using three observers would reduce it by about 42 percent, and using four observers would reduce it by 50 percent. The rate of gain from adding

TABLE 3. Density estimates[1] (birds/40 ha) as computed from data of each observer separately, all combinations of two observers pooled, and all three observers pooled. (Two standard errors are shown in parentheses below each estimate.)

	Density estimates						
Species	Obs. 1	Obs. 2	Obs. 3	Obs. 1+2	Obs. 1+3	Obs. 2+3	Obs. 1+2+3
Mourning Dove	4.2	1.9	3.4	3.8	4.9	2.9	3.3
	(1.7)	(1.1)	(0.8)	(0.6)	(0.7)	(1.0)	(0.7)
Acorn Woodpecker	7.3	5.3	7.3	5.7	6.0	4.5	5.4
	(2.2)	(1.7)	(1.3)	(0.6)	(1.4)	(0.5)	(1.1)
Ash-throated Flycatcher	9.0	8.9	13.7	9.1	10.5	9.1	14.2
	(3.2)	(1.4)	(5.5)	(2.1)	(2.7)	(2.2)	(3.0)
Scrub Jay	8.8	5.1	3.9	4.9	4.8	4.0	4.6
	(1.7)	(0.9)	(0.8)	(1.3)	(1.5)	(1.2)	(1.1)
Plain Titmouse	28.3	21.4	9.4	18.7	17.5	10.9	13.7
	(4.0)	(2.7)	(4.4)	(1.7)	(1.9)	(2.5)	(1.2)
House Wren	12.5	8.6	12.5	12.3	12.5	13.8	10.4
	(4.9)	(1.8)	(5.5)	(3.3)	(1.6)	(2.7)	(1.2)
European Starling	10.9	6.9	10.3	9.8	11.4	8.6	9.9
	(2.1)	(3.6)	(4.9)	(2.7)	(1.6)	(2.9)	(2.6)

[1]Estimates were computed only for species with a total count of 80+ by each observer, using the exponential polynomial estimator from program TRANSECT (Laake and others 1979), with observations grouped into 25-m intervals and truncated at 150 m.

observers beyond four is low enough that it probably would not be profitable.

Density estimates could be used to monitor trends only for the few species abundant enough to give the counts of 80 or more needed for these estimates. The sample could be enlarged to increase the count of every species, but to bring the count of all species to at least 80 in the present study would have required 16,800 counting stations (80 times that used). Any such alternative is unfeasible because of both cost and logistic constraints. Even if such an ambitious effort could be made, however, additional species would be detected, and at low total counts.

Total counts and frequencies appear to be the best measures for monitoring trends in bird populations. I was surprised to find, however, that frequency values of the three observers were as variable as total counts. Frequencies require only that the observer detect the presence of the various species at a location, but total counts require the additional step of detecting the number of each species, introducing more opportunities for observer error. Because total counts and frequencies are slightly different indices of population attributes, different statistical models would be applicable in their analyses. Whether or not this will make one of these two measures substantially less costly than the other remains to be determined.

I am optimistic that observer variability need not be as large as that found in this study. Although all three observers are widely acknowledged as experts in the identification of birds in the foothill pine-oak woodlands by sight and sound, Observer 3 (lowest total counts) is about 90 percent deaf in one ear and Observer 1 (intermediate total counts) admitted to me long after the 1985 field season that an inordinate fear of the cattle using the habitats sampled probably influenced counting efficiency. More careful preselection of observers based on factors known to bias their ability to count birds, especially their hearing, should reduce observer variability. Further gains can probably be made with more intensive training than was given to observers before this study. However, whether or not such measures can overcome observer variability enough to allow monitoring with only one or two observers remains to be tested.

ACKNOWLEDGMENTS

I thank Ellen L. Hammond, Zev Labinger, and John C. Lovio for the field work for this study; and Reginald H. Barrett and Hartwell H. Welsh, Jr. for their review of the manuscript.

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Monitoring Small Mammal Populations in Oak Woodlands[1]

Reginald H. Barrett[2]

Abstract: Methods for monitoring long-term trends in the abundance of smaller mammals, including small carnivores, include the use of animal sign, track plates, pit traps and direct observation. A suggested sampling scheme consists of a 1000-ha grid with 100 stations at 300-m intervals. Each station would be operated for 5 consecutive days. Once a site was established, each sampling session would require the work of one person for 10 consecutive days. Sampling should occur annually during the dry season on at least 15 sites established throughout the oak woodland zone of California. The Fisher Randomization Test can be used to detect significant trends in detection rates. This scheme should be reconsidered after pilot testing.

Landscapes are increasingly being modified by man, and resource managers are confronted with the need to monitor a variety of resources in a timely fashion to ensure that important ones are not irreparably lost or damaged. Over 100 species of smaller mammals form an important component of the wildlife community of oak woodlands in California (Barrett 1980). These woodlands, or "hardwood rangelands," are being modified by such things as urbanization, fuelwood cutting, burning and grazing (Mayer et al. 1986).

In this paper I consider monitoring to include only the detection of trends over a long period of time. The goal of monitoring is to ensure that important resources are not seriously damaged or lost due to currently unpredictable causes. Experiments to test hypotheses about responses of wildlife to specific habitat treatments will not be considered here (see Eberhardt 1978, Hayne 1978).

While our knowledge of wildlife-habitat relationships is expanding, many environmental factors other than visible changes in vegetation may govern the abundance of wildlife (Laymon and Barrett 1986). Biocides and predation are two obvious examples. Thus, although managers may be able to infer changes in the community of small mammals by monitoring major changes in the vegetation, there is still a need to monitor wildlife directly in a number of randomly selected sample areas. The problem is that any method of monitoring wildlife is considerably more costly than monitoring vegetation. Ideally one might hope to monitor the density of a small mammal on a monthly basis over a series of sample sites of many hectares each. Such effort has rarely been expended even in experimental research projects. A practical monitoring scheme for detecting long-term trends must be restricted to obtaining some index to abundance at a certain season.

My objective here is to briefly explore some options for monitoring the relative abundance of smaller mammals in oak woodlands, to discuss sample size requirements, and to suggest a practical monitoring system.

METHODS FOR ESTIMATING ABUNDANCE

Animal Sign

Small mammals such as moles, voles, gophers, woodrats, ground squirrels and rabbits leave species-specific sign that can be counted (Davis and Winstead 1980, Davis 1982). Research projects involving "double sampling" (Seber 1982) of the density of the animals as well as their sign have have shown that there may be a reasonable correlation between sign and animal density (Anthony and Burns 1983). Many more such studies are needed. Meanwhile it is probably reasonable to assume that a positive relationship exists between the density of sign and animal density for unstudied species.

Small carnivores can be detected by attracting them to track stations where species-specific tracks may be identified (Barrett 1983, Clark and Campbell 1983). Of course small mammals may also be detected this way (Raphael et al. 1986). This method is similar to trapping but the animals are not captured.

Trapping

Most studies of small mammals have used snap traps or box traps of some kind, depending on whether the animals are to be captured dead or alive (Smith et al. 1975). Live trapping is

[1]Presented at the Symposium on Multiple-use Management of California's Hardwood Resources, November 12-14, 1986, San Luis Obispo, California.

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preferred for studying animal density at frequent intervals, whereas snap trapping is typically less costly. Traps for larger species, such as raccoons or coyotes, are too cumbersome or too expensive for a monitoring program.

Pit traps (2-10 liters) may be used to capture small mammals and are particularly effective for shrews (Pankakoski 1979, Beacham and Krebs 1980, Dedon and Barrett 1982). Animals may be captured alive or dead, and pit traps may be baited or unbaited. Barriers may be used to increase the efficiency of pit traps. They are expensive to install initially, but once in place they may be covered and reused with less effort than required to set out snap or live traps. Barriers may be rolled up and stored in the pit traps when not in use (Raphael and Barrett 1981).

Direct Observation

A few species, especially the diurnal squirrels, may be sampled directly using methods more commonly used for birds or large mammals. Such methods include time-area counts (Davis 1982) and line-transect counts (Anderson et al. 1979). Species such as tree squirrels may be detected more readily by stimulating them to call.

SAMPLE SIZE

As indicated above, one is unlikely to measure animal density directly in a monitoring program, rather some type of catch-per-unit-effort or frequency-of-occurrence index would be obtained. Although it would be good to know the relationship between the index and true density, comparisons of indices over time should be done on the original data. The type and amount of effort expended should be carefully standardized (Caughley 1976:12-25).

The number of sample sites considered should be dispersed throughout the total area of oak woodland (Green 1979). For example, to monitor the state of California, but still be able to track regional differences, I suggest that at least three sample sites be allocated to each of the following regions: north coast, south coast, northern sierra, southern sierra, southern California.

The number of stations per sample site should be a function of the precision desired in detecting trends. This in turn is affected by the "detectability" of a species by a given sample method and the sample period each station is operated. For most species in oak woodland, the optimum prescription for these variables is not yet known. Hence pilot projects should be done before settling on a final standard. For example, one should run tracking stations for 10 or more nights to see if the cumulative number of stations visited levels off (Raphael and Barrett 1981). In most instances leveling off should occur, so the inflection point of the curve could be used to indicate the optimum sample period.

The next step is to determine the likely frequency of occurrence of the rarest important species expected. Some species will always be so rare (long-tailed weasel, Mustela frenata), or so difficult to detect with any known method (bats), that monitoring their abundance will simply not be feasible. For example, imagine that spotted skunks (Spirogale gracilis) typically visited 12 of 100 track stations even after a 5-day sample period. To detect a decline (alpha = 0.05; beta = 0.20; two-tailed Z test) in skunk abundance, the frequency would have to drop to only 1 of 100 stations visited (Davis and Zippin 1954, Fleiss 1981) (Table 1). Although a Z Test or a Wilcoxon Signed Rank Test is appropriate for determining significant trends in such data, the Fisher Randomization Test is preferred (Roughton and Sweeny 1982). Roughton and Sweeny provide a listing of the FORTRAN source code to accomplish all these tests. The important point here is that if a species is normally detected at less than 10 percent of the stations, it will be difficult to show a statistically significant decline.

If more sample stations are desired, the area of the sample site must be increased, given a constant distance between stations. The relationship between the size of the sample site and the distance between sample stations is indicated in Table 2. The home range of the largest species of interest should guide the distance between sample stations. Stations should be far enough apart that finding one is unlikely to influence an individual animal's finding another. Thus, if carnivores are being

Table 1. Examples of the ability of a pair of 100-station samples to detect a significant (alpha = 0.05, beta = 0.20, two-tailed test) change in visitation rate (Fleiss 1981:41-42). The visitation rate must drop from the first value to the second value or less to be considered a significant decline.

Stations visited first year	Stations visited second year
12	1
14	2
16	3
18	4
19	5
27	10
33	15
39	20
51	30
61	40
71	50

Table 2. Relationship between the area of a sample site and the distance between grid stations for a 100-station grid.

Between-station distance (m)	Grid area (ha)
10	1
100	100
316	1,000
1,000	10,000

considered, sample stations should be hundreds rather than tens of meters apart.

Frequency of sampling is another issue. Theoretically it would be preferable to sample once per year during the season at which populations were least variable (typically just prior to the reproductive season). However, given the difficulty of running pit traps and track stations during rainy periods, the summer season is the only feasible one. Moreover, this is the season when qualified labor, in the form of students, is most readily available. Nevertheless, we still need detailed studies of the annual cycles of many smaller mammals in oak woodlands. Furthermore, many species show marked fluctuations between years. Knowledge of normal patterns would greatly assist the interpretation of data derived from a monitoring program.

PROPOSAL FOR A STANDARD MONITORING SYSTEM

This proposal assumes that it is not feasible at this time to monitor bats and certain very rare species such as the long-tailed weasel. It also assumes that sample areas are preferentially located in flat to moderately steep sites within a short distance of vehicle access. It further assumes that 100 sample stations are sufficient to provide the desired precision and 300 meters between stations is sufficient for visits by larger mammals to be independent occurrences among stations. Such a grid laid out as a square would cover approximately 1000 ha. One track plate (Barrett 1983) would be established for 5 nights at each station. Additionally, one 5-gal pit trap (Dedon and Barrett 1982) would be established 150 m beyond each track station along one axis of the grid, thus making 2 grids offset by one half grid cell. Pit traps would also be run for 5 nights. Individuals captured in pit traps would be marked or removed to avoid double counting. Finally, sign of certain species (e.g. gophers) would be recorded if present within a 10-m radius of each pit trap. Tree squirrels and ground squirrels would be recorded if observed while walking between each track station.

One person should be able to complete one sample site in 10 consecutive days of work. Two lines would be established each day for the first 5 days (7 km walked per day). Then on the 6th day the first two lines would be checked, and so on until the last two lines were checked on the 10th day. Of course, initial establishment of the grid would require considerably more work to survey the grid and to dig in pit traps. Once established, nearly all equipment could be left on site. Pit traps would be covered and track plates could be buried. All stations would be marked with permanent survey markers.

CONCLUSION

I will conclude with two questions. Is it time to institutionalize a monitoring program for nongame mammals as is done in some European countries? If so, is the scheme outlined here the optimal design? Only a pilot project will determine this. In any case, there is certainly a need for further research on monitoring methodology, as well as additional autecological studies.

Acknowledgments: I thank Jared Verner and the Monitoring Subcommittee of the California Interagency Wildlife Task Group for a series of stimulating discussions on wildlife monitoring. Daniel F. Williams and David Sharpnack provided constructive criticism of an earlier draft.

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Managing Blue Oak for Wildlife Based on Acorn Production[1]

Laurence A. McKibben and Walter C. Grave[2]

Abstract: Acorn production for individual blue oak trees was determined by the visual-estimate method. Production was also measured by weighing the entire acorn crop of selected trees. The mean weights of acorns produced by individual trees in Classes 2, 3 and 4 were calculated. Analysis showed a statistically significant difference in acorn weight per square meter of canopy and per individual tree among Classes 2, 3 and 4. An individual tree must produce an annual acorn yield in Class 3 or 4 to provide a meaningful amount of food for wildlife.

Of the 17 species of oaks that occur in California (Tucker 1980) blue oak (Quercus douglasii) is among those of greatest concern because of its extent, utilization and apparent lack of regeneration. Moreover, blue oak is the primary species that ranchers clear from their lands to increase grazing capacity and generate income. It is the dominant tree in the oak woodlands surrounding the inland valleys and Coast Range.

In response to these pressures and concerns, the California Department of Fish and Game initiated studies of wildlife dependency on oaks in 1974 (Graves 1975). The original objective was to determine relationships between oaks and wildlife in order to develop habitat management plans. However, it became apparent early in the study that to achieve the objective a method was needed to monitor acorn yield. This paper briefly describes that method, evaluates its precision, and provides management recommendations based on a 10-year study using this method.

Methods

A permanent study area was established in blue oak habitat in the eastern foothills of Tehama County (Figure 1). Three hundred sixty-three trees on a 24,300-ha ranch were selected and marked **in** 1977. A survey route was established along roads to accommodate large areas and to ensure sampling efficiency. Sample plots were established at 0.32 kilometer intervals and five trees were selected randomly at each stop. Tree selection alternated from right to left along the road to facilitate random selection. Trees were selected at various distances from roadways depending on their availability but far enough to avoid unnatural edge effects. The dbh, crown diameter, height, and canopy depth of each tree were estimated and recorded. Because mast production may vary by slope and elevation, plots included trees on various slopes and at different elevations but these were not equally represented in the sample. Visual estimates of the acorn production were then recorded annually for each tree prior to the acorn drop from 1977 through 1985.

Acorn production for individual trees was determined by the visual-estimate method (Graves 1980). Trees were assigned to one of four classes according to the following procedure.

Class 1 - No Visible acorns (Score 1).

Class 2 - Acorns visible after very close examination. Maybe only one or two were observed (Score 2).

Class 3 - Acorns were readily visible, but they did not cover the entire tree and the limbs did not appear to bend from their weight (Score 3).

Class 4 - Acorns readily visible and covering the entire tree; limbs appeared to sag from weight of acorns (Score 4).

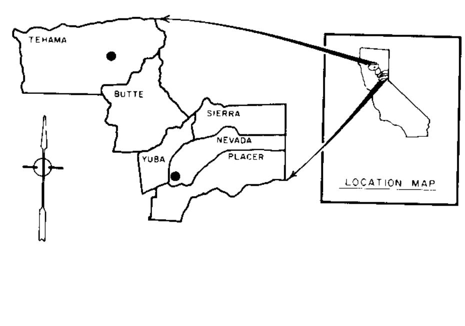

Figure 1-- Tehama Study Area, Tehama County and Spenceville Wildlife Area, Nevada County, California.

[1]Presented at the Symposium on Multiple-Use Management of California's Hardwood Resources, November 12-14, 1986, San Luis Obispo, California.

[2]Wildlife Biologists, Department of Fish and Game, Sacramento and Yountville, California.

Information collected early in the study showed that the best period, phenologically, to estimate mast production was between August 15 and September 15.

To determine the total weight of acorns produced per square meter of canopy and per tree, 10 Class 2 trees, 20 Class 3 trees, and 10 Class 4 trees were sampled on the Spenceville Wildlife area in Nevada County (figure 1). The entire acorn crop was collected from these trees and weighed within 24 hours after being collected to reduce variation in weight due to moisture loss. The same tree measurements were taken for these trees as for those at the Tehama study area.

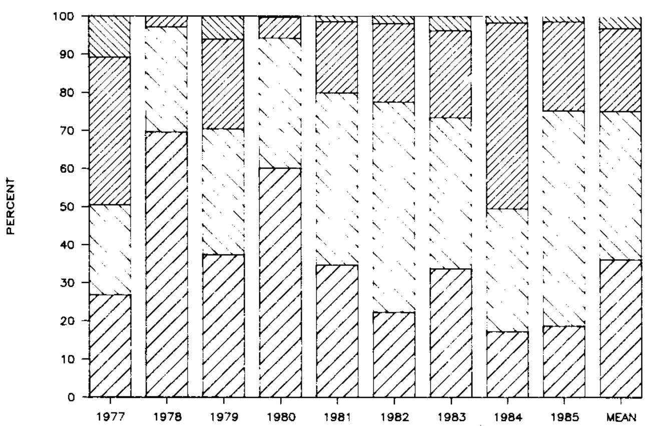

Figure 2-- Blue oak acorn yield class distribution in Tehama County, California from 1979 to 1985. Visual classes designated as follows 1 2 3 4

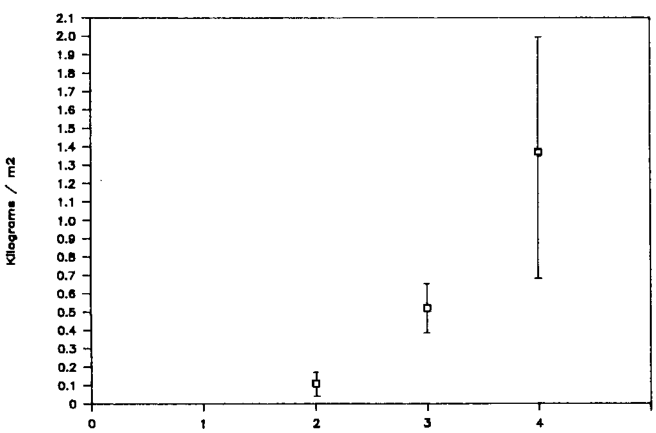

Figure 3-- Mean weight and 95 percent confidence intervals of blue oak acorn crop per m^2 of canopy by visual class.

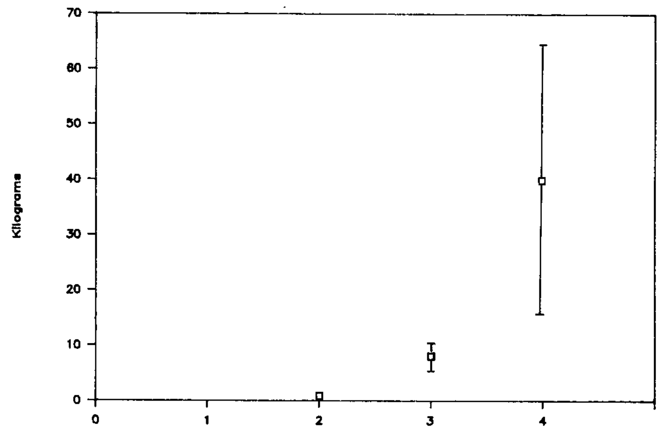

Figure 4-- Mean weight and 95 percent confidence intervals for total blue oak acorn crop per tree by visual estimate.

Results

The average acorn yield class for blue oaks on the Tehama study area ranged from 1.35 in 1978 to 2.34 in 1984 (figure 2). The 9-year average was 1.93. During this same period, 15 trees (4 percent) were rated Class 1 and 73 (20 percent) were rated Class 2 in all years. Thus, nearly 25 percent of the total sample was essentially non-productive during the entire study. The long-term trend showed that, on the average, only 25 percent of the trees were Class 3 or better in good production years.

Analysis showed a statistically significant (P=0.05) difference in acorn weight per m^2 of canopy between classes (figure 3). Acorn production was highest in Class 4 with 1.37 kg/m^2. The mean for Class 3 was 0.52 kg/m^2. The Class 2 mean was 0.11 kg/m^2.

A second important measurement that supported the value of the visual estimate method was the mean weight of acorns produced per tree in each visual class. As with the weight per square meter of canopy, all tree classes differed significantly from all others (figure 4). Class 2 trees produced a mean of 0.80 kg of acorns per tree; Class 3 trees averaged 8.01 kg per tree and Class 4 trees averaged 40.53 kg per tree.

Management Recommendations

Many landowners would like to harvest various amounts of oak trees on their land. By visually estimating annual acorn production and classifying individual trees, landowners can remove selected non-productive oaks and still provide acorns for wildlife in specific areas. Trees need to be visually classified and marked according to acorn yield class during one or preferably two high acorn production years. The percentage of trees producing at least 1 year at the Class 3 level increases with the number of years classified. Based on the Tehama County information, a good year would be defined as one in which 25 percent are producing as Class 3 trees or better in a random sample of 100 trees. Once producing trees have been identified, all or a portion of the non-producing trees (Class 1 and 2) can be removed. This probably would reduce competition between trees for nutrients and moisture although this has not been tested. This recommendation, of course, is based only on the value of oaks for mast production and does not consider other values.

When landowner goals are to improve the land for wildlife, only a small percentage of the non-producing trees should be removed. Furthermore, slash should be piled to provide ground cover for many game and nongame species. In some areas, when blue oak trees are harvested in winter, they have a greater tendency to sprout (Thornton 1980). Sprouts provide browse for deer and may become shrub-like in form to add diversity and ground cover.

Landowners wishing to remove as many trees as possible to meet management objectives could conceivable harvest all of the non-producing trees. Up to 75 percent of the trees in a given area could be removed without a significant loss (less than 10 percent) in acorn production. The actual percentage of trees to be removed would vary from area to area and must be determined by visual surveys, preferably for several years. In Tehama County during the best years, half of the trees were Class 3 or 4. This occurred in 2 of the 9 years for which data were collected. If a landowner had classified the trees during those 2 years, only half would have been marked for removal.

This method addresses only one element: acorns as food for wildlife. Greater oak densities may be necessary to provide cover for some wildlife species. Also, a good oak management plan needs to allow for recruitment of acorn-producing trees over time by leaving immature (too young to produce acorns) trees in the stand when they are present.

For larger areas such as counties, deer herd units, or geographical regions, annual acorn yield data can be used with other information such as herd composition counts, population surveys and food habits to explain or predict trends in wildlife numbers. Monitoring acorn production annually will provide quantifiable data on one of the many variable affecting wildlife populations.

An individual tree must produce an annual acorn yield in the Class 3 or 4 category to provide a meaningful amount of food for wildlife. For blue oaks, it is more important to show the frequency distribution of each class in the total sample than to simply refer to the average class. This is very critical when using yield classes to manage oaks for wildlife or making predictions on the value of the annual acorn crop to wildlife in any given area. For example, in a sample of 100 trees, when all the trees are Class 2, the yield would be 2. The total acorn yield would be 80 kg per tree. The same sample with a class average of 2 but with 50 Class 1 and Class 3 trees would yield 400 kg per tree--a five-fold increase in yield with the same class average. The difference would be even greater if Class 4 trees were included in the sample. By examining class frequency, we also identify the non-producing segment within the area over time.

To use this type of information to manage specific areas, annual acorn yield estimates should be used along with the average weight per square meter of canopy per visual class to estimate the pounds of acorns available for a given area. On private lands, this information can be an important consideration in setting harvest levels for pigs and deer.

Acknowledgments

We thank Jared Verner, Pacific Southwest Forest and Range Experiment Station, U.S. Forest Service; William Laudenslayer, Tahoe National Forest, U.S. Forest Service, and Ken Mayer, Forest and Rangeland Resources Assessment Program, California Department of Forestry for their review and helpful comments.

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Wood Products-Utilization

Gen. Tech. Rep. PSW-100. Berkeley, CA. Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1987.

Utilization Opportunities for Hardwoods[1]

Peter C. Passof[2]

Multiple-use management clearly implies that California's hardwood resources have important benefits and values whether left standing or converted into primary or secondary products.

California's native and exotic hardwoods offer a wide range of utilization opportunities. In the following papers you will learn how various hardwoods may be exploited for their organic compounds (silvichemicals), chips, fuelwood, low value boards and high value products such as those used in fine furniture.

For as many reasons as there are potential useful products for these hardwoods, most Californians have maintained a cautionary attitude toward increased utilization, preferring to wait on the threshold. Some have ventured forth with exciting ideas and even a smaller number have put their time and energies into practice.

Making a decision to utilize a specific species of hardwood whether it be for furfural, firewood, furring, or furniture is one that requires gathering up information from many sources and evaluating it carefully. For those entrepreneurs who have been less than successful in utilizing hardwoods, perhaps the ideas put forth in the following papers will shed new light and bring opportunity. For those still waiting in the wings, view the information as another important step in your data gathering process.

Public concern has been expressed that some species of hardwoods are being overutilized [sic], and may in fact be reaching a point where the situation is unacceptable in multiple-use management schemes because it ignores basic conservation principles. A successful hardwood utilization operation is one that understands the limits of the resource as well as the marketplace.

Our knowledge base concerning the wise management, protection, and utilization of California's hardwood resources has definitely increased since the last statewide symposium. More studies are underway which will provide you with even better information in the future. For those who need the information now, the papers in this section provide a full spectrum of up to date thinking.

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[1]Presented at the Symposium on Multiple-Use Management of California's Hardwood Resources, November 12-14, 1986. San Luis Obispo, Calif.

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Gen. Tech. Rep. PSW-100. Berkeley, CA. Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1987.

Overview of the Hardwood Utilization Problem[1]

Stephen L. Quarles[2]

Abstract: The hardwood resource in California is comprised of a wide variety of species including some in fairly sizable quantity. Despite this, significant utilization of this unique resource has never taken place. This paper discusses the most likely future utilization in terms of volume and wood properties. These are compared to the other commonly used species in the United States. Factors limiting the utilization of California hardwoods are discussed including processing and marketing problems.

During the last 30 years there have been numerous research papers reporting on various physical properties and processing characteristics of the major California hardwoods. Participating institutions have included the University of California and United States Forest Products Laboratories and the Forest Resources Laboratory at Oregon State University. During the same period, there have been many efforts made to establish and sustain a hardwood utilization industry in California. These efforts have included two major feasibility studies including the Hoopa Valley Reservation Hardwood Study Report (1968) and another by Winzler and Kelly Consulting Engineers (1979). Each of these investigated the economic potential of developing a hardwood utilization facility in the North Coast region (Humboldt County) of California. To date, little has come of these studies, both of which indicated that such an undertaking was economically viable. In fact, with the exception of Cal-Oak in Oroville, most of the larger facilities have ceased operating.

The reasons for the lack of greater hardwood utilization in California are somewhat complicated. There are definitely some processing problems associated with the primary breakdown with respect to sawing for grade, and with the drying operation, but exactly to what extent these problems can be traced exclusively to the fact that operations are geared toward the better known softwood processing procedures is difficult to say. It is also clear that well defined supply channels to some of the larger users in the state do not exist. In the remainder of this paper, I will expand on these ideas, and attempt to define issues that should be addressed in order to increase utilization of the California hardwood resource.

VOLUME COMPARISONS AND PHYSICAL PROPERTIES

Forest Service Report Number 23 (1982) reported that approximately 90 percent of our nations hardwood growing stock is located in the Southern, Eastern, and Midwestern states. Only 6.6 percent is located in Pacific Coast states, which amount to 16,866 million cubic feet. The most recent survey of California hardwoods estimates a timberland volume of approximately 7700 million cubic feet[3]. This represents approximately 46 percent of the 1977 Pacific Coast volume figure. While it is clear that most of the US hardwood resources lie outside California, there is still a sufficient quantity on which to build a hardwood industry.

Four species make up 85 percent of the hardwood timberland volume in California. These species are California black oak (Quercus kelloggii), Tanoak (Lithocarpus densiflorus), Canyon live oak (Quercus crysolepis) and Pacific madrone (Arbutus menziesii). They comprise roughly 29, 25, 17, and 14 percent of the total volume, respectively[3]. California-laurel (Umbellularia californica) is the fifth most abundant species, comprising almost 4 percent of the timberland volume. Any major utilization effort must rely on one or more of these species.

The physical properties of these hardwoods have been documented in a series of University of California Forestry and Forest Products Reports (available from the University of California Forest Products Laboratory) and publications from other institutions, as previously mentioned. A comprehensive review and comparison of eastern and western hardwood properties can be found in the Hoopa Valley Reservation Hardwood Study Report (1968). A summary of physical properties is given here in Table 1. Properties of California hardwoods generally compare favorably with Eastern hardwoods, and it is not felt that these properties should limit utilization.

PROCESSING AND MARKETING PROBLEMS

Several problems currently exist which limit utilization. These can be divided into two distinct areas, the first dealing with processing problems, and the second dealing with marketing aspects.

[1]Presented at the Symposium on Multiple-Use Management of California's Hardwood Resources, November 12-14, 1986, San Luis Obispo, Calif.

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[3]Personal Communication, 1986, Charles Bolsinger, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Table 1--Selected physical properties of major California and Eastern hardwoods.

Species	Specific Gravity, Swollen Volume Basis	Volumetric Shrinkage, %	Bending Strength lb/in^2	Modulus of Elasticity, 10^6 lb/in^2	Compression Perpendicular the Grain, lb/in^2	Side Hardness, lb
Eastern white oak	0.68	16.3	15,200	1.78	1070	1360
Black cherry	0.50	11.5	12,300	1.49	690	950
Sugar maple	0.63	14.7	15,800	1.83	1470	1450
Yellow birch	0.62	16.8	16,600	2.01	970	1260
Yellow poplar	0.42	12.7	10,100	1.58	500	540
California black oak	0.49	10.9	7,150	1.03	524	870
California laurel	0.55	12.2	10,030	0.94	900	1305
Pacific madrone	0.65	20.5	9,270	1.64	525	1250
Tanoak	0.67	19.2	14,450	2.26	640	1455

Note: The Wood Handbook (1974) is the source for data on all Eastern hardwoods. California hardwood data is taken from information compiled by Dost (1969).

The three major processing areas include harvesting, log breakdown, and drying. Hardwoods cause problems in each of these areas, especially when compared to softwoods. Harvesting will only be briefly discussed here. It would tend to be a problem because of the lack of pure stands of any given hardwood species and because of the potential for lower quality material on the stump.

Cutting to optimize grade is an essential component for the financial success of any major operation, and should be emphasized over maximizing yield. Malcolm (1956) discusses in some detail methods which can be used to maximize high grade lumber from hardwood logs. Several newer programs have been introduced recently by the United States Forest Service which should help in processing some of the low quality, and potentially low recovery California hardwoods. One of these, System 6 (Reynolds and Gatchell 1982), was developed to aid in processing low quality, small diameter Eastern hardwoods, species which are probably no easier to process than those in California. The major end products of System 6 are standard sized blanks for use in furniture and cabinetry manufacturing. It is possible, and desirable, to also incorporate a firewood, and chipping operation into the System 6 process. In spite of the apparent advantages of System 6, no large producer has incorporated it into their production process[4].

Drying is the other processing aspect which make hardwood utilization difficult. Regardless of how hardwoods are dried, they require more care and longer drying times than commercial softwood species. Longer drying times exist whether the lumber is initially air dried, or dried green from the saw. To minimize degrade, all hardwood lumber should be air dried to approximately 30 percent prior to conventional kiln drying. This leads to higher inventory carrying costs, and is in that respect undesirable.

Drying schedules for the major California hardwoods have been published by both the UC and US Forest Products Laboratories. Theoretically, these schedules can be used to dry lumber from the green condition. The problem lies in the fact that low temperatures (around 110°F) and high relative humidities are called for in the early portion of the schedule. To avoid excessive degrade it is therefore critical to have a kiln which can hold close tolerances. It is generally difficult for conventional kilns to do this.

California black and other California oaks are generally no harder to dry than Eastern oaks, and all are susceptible to surface checking. Tanoak is the most difficult to dry of the California hardwoods, and it is debatable whether it can be successfully dried from the green condition in a kiln operating at conventional temperatures. Darker colored portions of the tanoak heartwood are extremely collapse susceptible, and the wood in general is prone to surface checking. Consistent high quality drying of tanoak is a critical problem which must still be overcome for successful utilization.

Several systems offer some hope for speeding up the drying of hardwoods, while maintaining a high quality end product. One such system involves the use of a predryer. These are relatively large chambers (a capacity of roughly 100,000 board feet) which operate at extremely low temperatures (85-95°F) and high relative humidities (75-80 percent). As with conventional kilns, fans are used for circulating air. Predryers are intended to be used as a controlled air drying yard. Lumber is

[4]Personal Communication, 1986, William Sullivan, Humboldt State University, Arcata, California.

dried to about 30 percent and then transferred to a conventional kiln for drying to the final moisture content. Use of predryers can therefore significantly reduce drying time and reduce degrade. Total time in the predryer is approximately one month. Dehumidification kilns have also been used successfully in hardwood drying and offer a good alternative to air drying. The success has mainly been due to slow heating up time and a relatively low maximum temperature, both of which are conducive to slow drying and consequently fewer defects. Certain changes in the dehumidification unit (specifically to the refrigerant) now make it possible to dry at temperatures used in conventional steam heated kilns. Dehumidification units so equipped become an attractive alternative for drying western softwoods, since drying time can be reduced relative to earlier dehumidification units. However with respect to hardwoods, they offer no additional product quality benefits over conventional steam heated units. In addition, equipment must be available to supply low pressure steam to the kiln for equalizing and conditioning the lumber, steps which are necessary to equalize the moisture content of the lumber in the kiln and to relieve stresses which develop during drying.

Some of the newer systems on the market involve vacuum drying in conjunction with either a heating medium such as heated platens or blankets, or with radio frequency heating. Many of these systems appear to give good results in terms of both drying time and quality, but independent verification is not available for these claims.

MARKETING PROBLEMS

There are several major marketing problems which hinder greater utilization. These include the lack of any continuous supply channels which would move the material from the primary to secondary processing facilities. There is also no formal outlet for technical information concerning secondary manufacturing processes such as wood machining and bending characteristics, although much of this information already exists. The furniture industry in California will always be leery of buying into the California hardwood market as long as there is no steady, consistent, supply.

In general, California hardwoods are single species. California black oak does not look like a typical eastern red oak. The same can be said for tanoak and Pacific madrone, in that they show little resemblance to eastern hardwoods. These species must stand alone, and really cannot be used as a look alike for a better known species. Only the California white oaks look like typical white oak. The fact that most of California hardwoods are stand alone species is not necessarily bad, but it does mean that some marketing effort is needed to "sell" these species. It would be helpful, in this respect, to adopt the same grading rules as used by the National Hardwood Grading Association (NHGA). Discrepancies between NHGA grading rules and Red alder grading rules, have apparently led to some confusion on the part of some secondary processors.

FUTURE UTILIZATION

It seems unlikely that any large primary processing operation will start up in the near future. One possible exception would involve an established eastern or midwestern hardwood producer to participate in a joint venture with an established west coast softwood producer with a sizable hardwood resource base[5]. The established hardwood producer would presumably provide processing expertise as well as access to markets. I am becoming more aware of one and two person operations which are operating throughout the northern part of the state. These operations are facing the same processing problems that any large operation would, and on initial start up, must wait up to a year to sell any dry lumber. In short and midterm, these small operations will likely continue, in addition to others starting up.

It seems prudent to nurture and support this developing cottage industry, especially since most of the larger operations have failed for one reason or another. The biggest problem faced by the small independent is drying the lumber. Developing one or more drying cooperatives would be one way to help alleviate this problem. It would be possible to take this idea one step further and establish a primary processing cooperative, where both primary breakdown and drying would be performed.

Secondary processing cottage industries which have the potential to develop around the primary processors include flooring (tanoak is ideal due to its exceptional hardness), cooperage (white oak would be best suited for the same reasons Eastern white oaks are used), furniture (all hardwoods), pallets and pallet stock, veneer, and firewood. Bill Dost, of the University of California Forest Products Laboratory, suggests that an ideal use of white oak cooperage would be for one to five gallon wine casks for sale at do it yourself wine shops.

In summary, the best short term potential for California hardwood utilization appears to be with the small but growing, cottage industry. It seems that resources would be best utilized by supporting the development of these concerns through the establishment of cooperative processing centers, especially for drying. A clearing house for transferring current technology to producers and users and to act as a middle man to match hardwood suppliers with potential manufacturing centers would help overcome some of the processing difficulties and also aid in establishing the necessary supply channels. Finally, an investigation of some of the cottage industry operations in the East may help realize our potential somewhat quicker, with fewer false starts.

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Ethanol Fuel, Organic Chemicals, Single-Cell Proteins: A New Forest Products Industry[1]

D. L. Brink, M. M. Merriman, and E. E. Gullekson[2]

Abstract: Production of a minimum slate of products; for example, ethanol, Torula yeast, furfural and process power using the hydrolysis-fermentation-combustion process has been shown to be both technically and economically feasible on a demonstration scale using New York hardwoods and California manzanita. Using the same conservative approach the minimum return on investment using a California hardwood feedstock at a rate of 600 OD tons per day also shows economic feasibility. The cost of fermentables at $0.097 per pound when wood costs are $30 per OD ton is competitive with other U.S. sources of sugar.

Our exceptional national capacity for production of organic matter, i.e., lignocellulosic materials (LCM) through silvilculture and agriculture, is an asset that can be brought to bear directly upon the national energy and chemical raw material shortages which are currently deceptively dormant. The ultimate need for diversification from a petroleum-based economy is inevitable. A prime candidate for implementing diversification involves the hydrolysis of LCM to intermediate soluble organic compounds and insoluble ligneous residues. These intermediates then serve as feedstocks to produce numerous products. The concept being presented in this paper is for an integrated process in which virtually all of these intermediate products will be utilized to produce a value. Furthermore, it is an objective to provide limited flexibility of the design that will allow for changes in the ratio of products. Thereby, return on investment can be maximized. In the base case presented the final products are single cell proteins and furfural for intermediates obtained by hydrolysis of hemicelluloses and ethanol from glucose obtained by hydrolysis of cellulose. Other products are recovered and used for their fuel value. Certain organic compounds in this fraction could be recovered as products having substantially higher values than that of a fuel. Development of one or more of the additional products could substantially enhance the base case presented here. Finally, numerous commercial fermentations other than for Torula yeast and ethanol are available for the production of products.

The economic conditions and petroleum supply vs demand have so drastically altered since 1973 that a threshold for initiation of a wood chemical industry is at hand. This is supported by advances that have been made in engineering and biotechnology which reduce the costs and broaden the range of products that can be produced.

[1]Presented at the Symposium on Multiple-Use Management of California's Hardwood Resources, November 12-14, 1986, San Luis Obispo, California.

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A program to utilize LCM in a new industry should have far-reaching salutary effects on local and national economies. Benefits include: the location of new industrial units in rural areas, particularly those which are economically-depressed; and the provision of new employment opportunities in the production units, in harvesting and silvicultural operations, and in ancillary businesses providing goods and services.

Improved forestry practices would include increased use of thinnings; logging residues; insect, fire, and incipient decay damaged wood; residues from primary and secondary lumber manufacturing and the new opportunity to utilize so-called weed species and brush.

It is the purpose of this paper to outline the results of a decade of work carried out at the University of California Forest Products Laboratory (UCFPL) in which a process has been designed for the hydrolysis of LCM and production of products therefrom using modern technology. Moreover, it will be shown that a process producing a minimum number of products which is specifically related to California hardwoods can be economically viable. This program, since 1979, has been carried out with cooperation and support from GeoProducts Corporation of Oakland, California.

LIGNOCELLULOSE

All cells of woody plants are composed of LCM which comprises the vast majority of terrestrial biomass. Extractive-free LCM is a mixture of two quite different types of biopolymers, i.e, polysaccharides and lignins. These biopolymers are laid down by the protoplasma of each cell in a sequence of layers that gives a complex interpenetrating system.

The principal component in the system, cellulose, is deposited first in linear molecules composed of five thousand to fifteen thousand D-glucose units linked by primary valence bonds. Accompanying or closely following the deposition of the cellulose, polysaccharides of a second class known as hemicelluloses are deposited. These hemicelluloses occupy interstitial space surrounding the cellulose fibrils, and penetrate small bundles of microfibrils. The molecules of hemicellulose comprise relatively short chains of

100 to 200 monosaccharide units. Some units in these chains bear other substituents or side-chains.

The major type of hemicellulose present in the angiosperms (hardwoods and grasses) is xylan comprising linear molecules of the 5 carbon (pentose) monosaccharide, D-xylose. Substituents on the xylan backbones include D-glucuronic acid and/or 4-0-methyl-D-glucuronic acid. In hardwood xylans the acetyl group is also a substituent; whereas, in softwood xylans L-arabinose (a pentose) is a substituent.

The major hemicellulose in gymnosperms (conifers or softwoods) is glucomannan comprised of two 6-carbon (hexose) monosaccharides, D-glucose and D-mannose, as backbone units. Of several glucomannan types in the softwoods, galactoglucomannans predominant. In this type, some glucose and mannose units in the linear chain bear the hexose, D-galactose, as well as acetyl groups, as substituents. Relatively small amounts of glucomannan, without substituents, are present in hardwoods.

The polysaccharides present in lignified tissues are hydrolyzed to monosaccharides by specific enzymes and by the hydrogen ion.

Lignin is deposited interstitially with or just after the deposition of the hemicelluloses. A portion of the lignin, particularly in softwoods, is chemically bonded to hemicelluloses but not to cellulose. Chemically, lignin is comprised of substituted benzene rings to which 3-carbon (propyl) side chains are attached. These arylpropane or C_6-C_3 units are interconnected at two or three sites per unit by carbon-to-carbon or carbon-to-oxygen-to-carbon (ether) bonds. Unlike the polysaccharides, the bonds linking the C_6-C_3 units into three dimensional high molecular weight lignin polymers are not significantly hydrolyzed by enzymes or by hydrogen ion, even at elevated temperatures.

Typical amounts of cell wall components found in extractive-free wood are:

Cell Wall Components	Angiosperms	Gymnosperms
	Percentage of Cell Wall Components	
Cellulose	42±3	42±3
Hemicelluloses		
Xylans	27±7	12±3
Glucomannans	4±2	20±5
Lignins	25±5	30±5

This lignocellulosic structure of interpenetrating polymers is the raw material or feedstock from which relatively simple chemical compounds can be produced and isolated as products. It is these products that can provide the basis for an organic chemical industry. In this paper the economic production of simple organic chemicals from California hardwoods is addressed. This activity holds the promise of a new forest products industry.

HYDROLYSIS OF LIGNOCELLULOSE

The polysaccharides of LCM are hydrolyzed readily by enzymes or by hydrogen ions when certain necessary conditions are present. The process requires the intimate contact of the large bulky molecules of enzymes with the surface of LCM where the glycosidic bonds involved in the linkages of the monosaccharides are hydrolyzed; i.e., the components of one molecule of water are added to each bond that is cleaved. The surface area of the polysaccharides that may be brought into such contact is limited even after reduction of the LCM to small particle sizes. Because excessive amounts of energy are required to reach particle sizes that substantially affect the rates of hydrolysis, the size reduction necessary is uneconomical.

The second means for hydrolyzing polysaccharides of LCM to monosaccharides employs the hydrogen ion as the catalytic agent. Hydrogen ion concentrations required to effect these hydrolyses may be obtained using concentrated mineral acids at essentially ambient temperatures or weak acids at elevated temperatures (Goldstein, 1981; Harris, 1949; Conner et al, 1985). The use of concentrateed mineral acid has been uneconomical for decades because of the technical problems and resulting high costs that are involved in the recovery and recycle of the acid. Our recognition of these limitations in the mid 1970's was the major consideration selecting weak acid hydrolysis as the method having the greatest economic potential.

It was known that the rates of weak acid hydrolysis of hemicelluloses are several times greater than that of cellulose (Saeman, 1945; Harris, 1975). Under conditions required for dilute acid hydrolysis, degradation of monosaccharides takes place at significant rates. Accordingly, to obtain satisfactory yields of hemicellulosic sugars as well as glucose from cellulose, two sets of hydrolytic conditions had to be used. Conceptually, in the process that was to be designed, hemicelluloses were to be hydrolyzed in a first stage. The resulting solution of sugars had to be removed from the lignocellulosic residue before appreciable acid dehydration of sugars could take place. Finally, the solid residue still containing most of the cellulose had to be subjected to more severe hydrolysis to produce glucose.

Criteria we considered as necessary to maximize the economic viability of a modern wood hydrolysis process in the United States included:

1. The use of a dilute mineral acid.
2. Minimal energy usage to procure and prepare the LCM feedstock.
3. Two or more stages of hydrolysis to maximize sugar yields.
4. Continuous flow of process streams.
5. Optimization of temperature, time, acidity, and number of hydrolysis stages to maximize production of specific products.
6. Production of those products in maximum yields which give highest return on investment for a given process design.

7. Production of process effluents and emissions that are environmentally benign for each process design.

UCFPL CONTINUOUS FLOW REACTOR STUDIES

Reactors were designed and constructed in our laboratory in order to conduct a multistaged continuous flow process study. The reactors were sized to process, nominally, ¼-, to ½ ton (OD wood basis) per day (24 hours). In the first stage the hemicelluloses were to be hydrolyzed, essentially quantitatively, the hydrolyzates were to be removed, and the partially hydrolyzed wood particles were to be treated with additional dilute acid and hydrolyzed in the second stage reactor. In this stage the major parameters, space time, temperature and hydrogen ion concentration were selected to rapidly hydrolyze the cellulose in order to optimize the yield of glucose and to minimize acid degradation of glucose to the initial degradation product, hydroxymethylfurfural (HMF).

An initial study was carried out using chips of white fir (*Abies concolor* Lindl. and Gord.) and Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco). Results met or exceeded predicted results (Brink and Merriman, 1980). Glucose, mannose, xylose and acetic acid in the first stage (S1) hydrolyzates, after pretreatments to remove the inhibitors and adjust pH, were readily utilized in aerobic fermentation to produce *Candida utilis*. This product is isolated and marketed as Torula yeast. Similarly, after pretreatments to remove inhibitors and adjust pH, the second stage (S2) hydrolyzate proved to be a good medium for the production of ethanol by anaerobic fermentation using the yeast, *Saccharomyces cerevisiae*.

A second study was carried out for GeoProducts under a contract with United Engineers and Constructors of Philadelphia, Pennsylvania, in which chips from four species of Eastern hardwoods were mixed and used as a feedstock. Again yields and other results obtained exceeded expectations.

Paper separated from municipal solid wastes was used as a feedstock in a third study. Cellulose was particularly high in this feedstock and this was reflected in the high yields of glucose obtained.

A fourth study was carried out for GeoProducts under a contract with the California Department of Forestry in which two species of California manzanita, Greenleaf manzanita (*Arctostaphylos patula* Green) and Common manzanita (*A. manzanita* Parry) were used as feedstock. This investigation proved to be equally successful relative to yields of products, operation of the continuous flow hydrolysis units, and fermentation of sugars present in the hydrolyzates. Second stage reaction kinetics and a computer simulated process flow were developed.

To demonstrate the technical and economic feasibility of the process as developed and the fermentability of the sugars in the hydrolyzates, a fifth large-scale demonstration project was carried out for GeoProducts under contract with the New York State Energy Research and Development Authority. In this study chips of seven predominant hardwood species were procured and mixed in a proportion that was judged to be typical of wood that is available commercially in the vicinity of Tupper Lake, New York,. These species were: American beech (*Fagus grandifolia* Ehrh.), sugar maple (*Acer saccharum* Marsh.), red maple (*Acer rubrum* L.), quaking aspen (*Populus tremuloides* Michx.), black cherry (*Prunus serotina* Ehrh.), yellow birch (*Betula alleghaniensis* Britton), and white ash (*Fraxinus americana* L.). Over two tons of wood (OD basis) were processed through the S1 reactor and the S1 residues isolated in this work were then processed through the S2 reactor. Four replicate S1 run series were carried out in which 57 steady-state intervals averaging 2.43 hours per interval were completed. A series of 16 S2 runs were carried out in which 42 steady-state intervals averaging 2.83 hours per interval were completed. Major variables studied included temperature, space time and pH. Second stage reaction kinetics developed in the fourth study were verified.

Hydrolyzates isolated in both S1 and S2 reactions were used in studies involving fermentation of component monosaccharides and recovery of various hydrolytic products and acid degradation products formed from the monosaccharides.

SIMULATED PROCESS FLOW

The process flow, given in figure 1, was simulated in essence in the fifth and most recent experimental study.

The analyzed composition of the mixture of New York hardwood chips used in the fifth study and the California manzanita chips used in the fourth study and an estimated composition of a mixture of California hardwoods that could represent a potential northern California supply are given in table 1.

The composition of the California hardwood mixture was calculated using three of the four most abundant species (madrone, *Arbutus menziesii* Pursh; tarroak, *Lithocarpus densiflorus* (Hook & Arn.) Rehd.; and California black oak, *Quercus kelloggii* Newb.) listed in a current inventory of the growing volume of hardwoods in California (Bolsinger, 1986) and for which a chemical composition was available (Pettersen, 1984). The "average" chemical composition of this mixture was taken as the summation of the composition of the three species, each weighted by the relative contribution each made to the total statewide growing volume of the three species.

Using the composition of California hardwoods (table 1) and the experimental results, including S2 kinetics, achieved with New York hardwoods in the fifty study allows the estimation of inter-

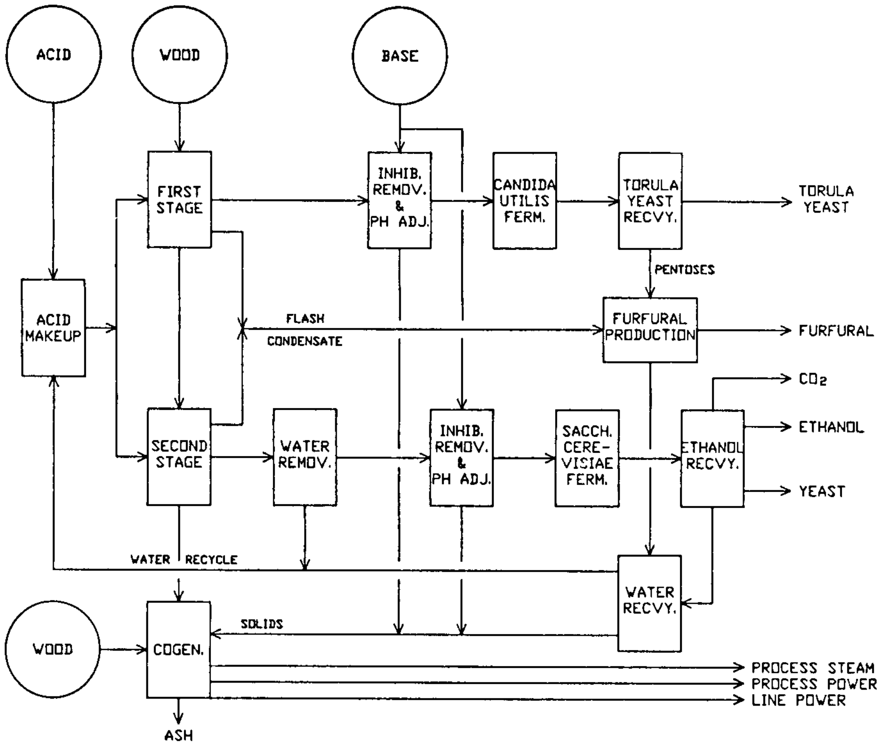

Figure 1--Process flow schematic for UCFPL-GeoProducts Hydrolysis-Fermentation-Combustion process.

Table 1--Composition of HFC process feedstocks.

Chemical components	New York hardwood 7-species mixture	California manzanita 2-species mixture	California hardwood 3-species mixture
		Percentage[1]	
Glucan	38.1	28.6	36.9
Mannan	1.9	1.4	2.0
Galactan	1.2	1.6	1.5
Xylan	14.9	16.4	19.3
Arabinan	0.6	1.9	0.5
Acid insoluble residue	23.6	32.9	20.7
Acetyl	3.8	4.0	4.0
Other organics	15.6	12.7	14.5
Ash	0.3	0.5	0.6
Total	100.0	100.0	100.0

[1]Oven Dried (OD) wood basis.

Table 2--Intermediate products of hydrolysis from California hardwoods.

Solid component	Slurry solids S1	Slurry solids S2	Hydrolyzate Component	Hydrolyzate Soluble solids S1	Hydrolyzate Soluble solids S2
	Yield pounds. per ton OD wood basis				
Glucan	700.4	196.9	Glucose	36	358.0
Mannan	0.0	0.0	Mannose	31.2	0.0
Galactan	0.0	0.0	Galactose	26.0	0.0
Xylan	25.5	0.0	Xylose	375.0	17.2
Arabinan	0.0	0.0	Arabinose	8.4	0.0
Acid insoluble solids	404.0	402.0		0.0	0.0
Acetyl	3.4	1.2	Acetic acid	106.9	7.7
Ash	0.9	0.9		11.1	0.6
Methanol	0.0	0.0		15.5	0.0
Furfural	0.0	0.0		23.9	18.7
HMF[1]	0.0	0.0		1.3	24.8
Levulinic acid	0.0	0.0		0.0	13.3
Formic acid	0.0	0.0		0.0	8.8
Other organics	200.8	199.8		114.2	158.1
Total	1335.0	800.8		749.6	602.2

[1]HMF is 5-hydroxymethylfurfural.

mediate product yields from hydrolysis of California hardwoods given in table 2. Based on the yields of intermediate products and known conversion efficiencies the final product yields can be calculated as shown in table 3. Assumptions used in calculating these yields include: 95 percent washing efficiencies; conversion of 100 percent of the glucose, mannose and acetic acid and 10 percent of the xylose in treated S1 hydrolyzate to give 50 percent yields of Torula yeast; 90 percent recovery of Torula yeast; overall recovery of 88 percent of furfural from S1 and S2 hydrolyzates and conversion of xylose in treated S1 hydrolyzate; and 46 percent recovery of ethanol from glucose in treated S2 hydrolyzate. By changing hydrolysis conditions the yields of intermediate products in table 2 and of final products shown in table 3 can be altered.

Table 3--Products predicted from HFC process utilizing California hardwoods[1].

Product	S1	S2	Total
Torula yeast	98.0	--	98.0
Furfural	207.5	12.8	220.3
Methanol[2]	9.0 (1.37)	--	9.0
Ethanol[2]	--	156.6 (23.8)	156.6
Brewers yeast		10.6	10.6
Subtotal			494.2
Hydroxymethylfurfural	1.1	21.1	22.2
Levulinic acid	0.0	13.3	13.3
Insoluble solids (S2-residue)			800.8
Soluble solids			602.5
CO_2 (ethanol fermentation			152.9
Total output products			2083.9

[1]Pounds per ton of wood feed (OD basis).
[2]Gallons in ().

PROCESS ECONOMICS

A database has been developed for the HFC process which has been used to estimate with high confidence the economic feasibility of a two stage process for New York hardwoods and California manzanita. Given the chemical composition of a different lignocellulosic feedstock (e.g. the 3-species California hardwood mixture in table 1), the predicted intermediate product yields (table 2) and the final product yields for the simulated process (table 3), then the estimated gross revenues from products produced in the simulated HFC process were calculated for a 600 OD ton per day (tpd) plant and are given in table 4. Values are based upon 330 days of production per year and current or projected market prices. Though the current price for furfural is 50 to 100 percent higher, it may be predicted that increased production will increase its use and lower its price to that given. Ethanol is used primarily as an octane enhancer in gasoline and its price is linked to the price of crude petroleum and, also, of corn from which it is produced. Thus, its price fluctuates widely and unpredictably. With the inevitable rise in crude petroleum costs the price given for ethanol may be expected to rise. The amounts of methanol and brewers yeast produced are trivial but the products are formed, will be produced and enjoy good markets and, therefore, have been included.

In addition to these five products 5-hydroxymethylfurfural and levulinic acid are produced, can be isolated on a practical basis, and could enhance the profitability of the process. These two chemicals have been included in table 4 with an estimated gross value to indicate the magnitude of the increase in gross revenue they might contribute using a comparatively low price for this type of organic compound. Elsewhere in this paper it is assumed these two products are combined with other organics and formic acid listed in the hydrolyzates in table 2, assigned a fuel value, and together with the insoluble ligneous residue enter into the credit given for power developed in cogeneration.

Table 4--Estimated gross revenue from products[1].

Product	Market price $/lb (gal)	Lbs (gal) per year millions	Gross value, $ millions
Torula yeast	[2]0.30	19.41	5.82
Furfural	0.30	43.62	13.09
Methanol	(0.70)	1.79 (0.272)	0.19
Ethanol	(1.25)	31.03 (4.71)	5.89
Brewers yeast	0.30	2.11	0.63
Total		97.95	25.62
Hydroxymethyl-furfural	0.50	4.39	2.20
Levulinic acid	0.50	2.24	1.12
Total		104.58	28.94

[1]Yields based upon 600 OD tons of wood per day.
[2]Feed grade; food grade is currently about $0.50-0.60/lb.

The return on investment (ROI) predicted for a 600 tons per day HFC plant utilizing California hardwoods is given in table 5. The estimated operating expenses, other than wood costs, including operating labor, maintenance, maintenance materials, chemicals, taxes and insurance and overhead, are fixed. The two variables most affecting ROI are the costs of wood and the price of ethanol. Sensitivity analyses were carried out to predict the effects of these two variables on the estimated profitability of this plant. In figure 2 the affect of the cost of wood on ROI is given assuming no and 4 percent inflation and an ethanol price of $1.25 per gallon. In figure 3 the affect of the price of ethanol on ROI is given assuming no and 4 percent inflation and a wood cost of $30 per OD ton.

Table 5--Return on investment for 600 OD ton per day HFC plant.

1.	Gross revenue	$, millions	
	Five product plant	25.6	
2.	Operating expenses	6.1	
3.	Wood costs at $30/ODT	5.9	
4.	Total investment	59.2	
5.	ROI[1] - No inflation		15.5 pct
	4 pct inflation		19.1 pct

[1]Assumes federal tax rate 33 pct, net state tax rate 7 pct, depreciation 15 yr. double declining balance.

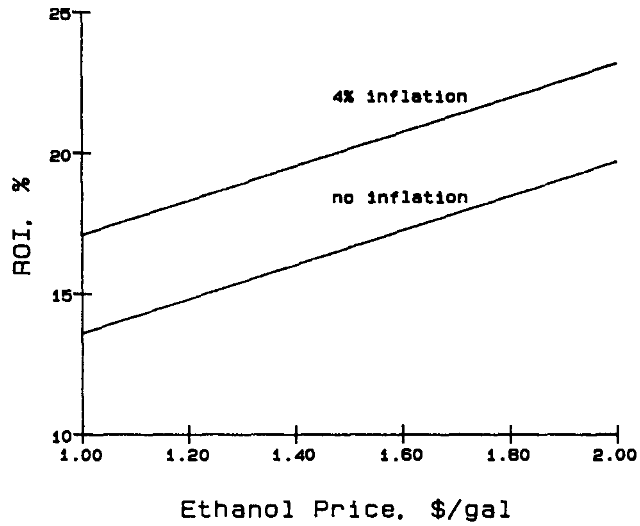

Figure 3--Influence of the price of ethanol on ROI of the HFC process. Wood cost at $30/ODT.

Another measure of the economic feasibility of this process is the cost of the intermediate fermentable products. The yields of the five sugars and acetic acid recovered in the S1 and S2 hydrolyzates are calculated from table 3 on an annual basis. The unit cost per pound of the recovered products is then estimated from the investment in the hydrolysis plant and the operating expenses required to produce the specified intermediate products in the hydrolyzates treated and ready for fermentation. Results of these calculations are given in figure 4 using variable wood costs.

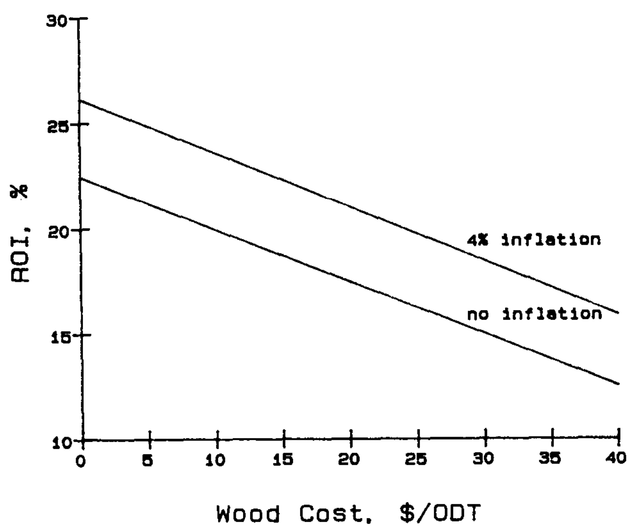

Figure 2--Influence of wood cost on ROI of the HFC process. Ethanol price at $1.25/gal.

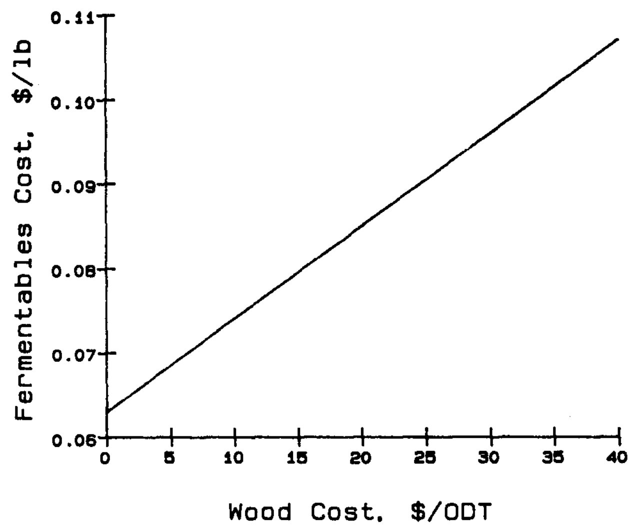

Figure 4--Influence of wood cost on the cost of fermentable products from hydrolysis.

DISCUSSION

Based on the extensive database developed for the HFC process, particularly with New York hardwoods and California manzanita feedstocks, it is now possible, using the process flow developed experimentally and modeled in a computer program, and the kinetics developed for hydrolysis, to predict product yields for a lignocellulosic feedstock of a known composition. This has been done and is presented here using a mixture of California hardwood species.

The feedstocks in table 1 are given on a whole wood basis. The analyzed New York hardwood mixture is mostly bark-free whole wood, the analyzed California mixture is whole stem chips including bark, and the estimated California hardwood mixture is calculated on a bark-free wood basis. In practice a feedstock will include a varying amount of bark.

Final products from the process flow, figure 1, are listed in table 4. The five products subtotaling 494.2 pounds are considered as those that would be first produced and provide the basis of the economic estimates made herein. HMF and levulinic acid could be added to the product slate with relative ease but market development will be required for these two chemicals. Carbon dioxide is a product that represents 48.8 percent of the weight of a hexose on fermentation to ethanol. Under appropriate conditions it could be recovered as a commercial product.

The estimated gross revenue from a plant utilizing California hardwoods, table 5, is subject to change in market prices of the commodities that would be produced as discussed under Process Economics. The prices used are considered to be conservative. The most difficult to predict, ethanol, provides 23 percent of the gross revenue. This could be increased substantially by fermenting the pentose as well as the hexose sugars in the S1 hydrolyzate to ethanol. The fermentation of pentoses as well as hexoses by microorganisms, such as Pachysolen tannophilus, is rapidly approaching commercial feasibility. If the hexoses in table 3 were converted in 47 percent yield and xylose was converted in 40 percent yield, about 56 gallons of ethanol could be produced per ton of feedstock. However, no Torula yeast, only 29.2 pounds of furfural, plus 27.8 pounds of brewers yeast would be produced per ton of feedstock. On the other hand ethanol fermentation could be replaced by one of several alternative uses of glucose in the S2 hydrolyzate. Thus, there is considerable flexibility in selecting the products to be produced from the intermediate products listed in table 3.

The ROT of 15.5 percent given in table 6 for a 600 tpd plant producing the five products discussed and using wood costs at $30 per ton delivered to the plant site and no inflation, shows that this process is economically viable. This is considered particularly significant since conservative estimates have been made throughout this evaluation. This viability is further indicated in the sensitivity analyses given for wood costs (figure 2) and ethanol prices (figure 3). As new products are added ROT can be considerably enhanced.

The second estimate made of economic feasibility is indicated by the analysis of the cost of fermentables (i.e., glucose, mannose, galactose, xylose, arabinose and acetic acid). The sensitivity of these costs to wood costs, given in figure 4, shows the process is economically competitive with sugar from other sources. A value of about $0.10 per pound is competitive in the United States.

A system of the kind described could be put into operation in any region in which there are sufficient hardwoods to sustain a feedstock of 600 OD tons per day. Coupled with such a plant a sawmill utilizing the logs of a grade to produce lumber would provide an integrated operation such as that currently enjoyed by pulp mills and lumber mills. A number of potential sites could be selected in California for such an integrated operation. The benefits that would accompany a development of this kind are discussed in the introduction. A major benefit and one that would have an immediate impact concerns employment. It is estimated that a plant of the kind described would directly employ 100 persons. An additional 60 people would be employed in the woods operations supplying the feedstock. Also, other employment would be generated in the service industries and activities ancillary to the plant and woods operations.

Production units of this kind would have, in particular, salutary effects upon silvicultural operations. Thinning, recovery of otherwise unmerchantable wood, and utilization of brush species, which were previously uneconomical, could be practiced.

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The University of California's Woody Biomass Extension and Research Program[1]

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Abstract: In response to the energy crisis in the early 1970's, the University of California became involved in an integrated research and extension effort to evaluate woody biomass plantations. The genera Eucalyptus has been determined to be the most promising on a statewide basis. 20 research/ demonstration plots range in growth from 6 to 30 tons per acre per year. Clonal propogation of Eucalyptus has been greatly advanced, and several promising clones have been released to private nurseries. A financial and biological growth model for Eucalyptus has been developed as well as preliminary data on spacing, weed control and fertilization. Future work on identification of genetically superior trees and establishment of improved seed orchards is anticipated, as well as an expanded effort in harvesting technology and market development.

HISTORICAL DEVELOPMENT OF A BIOMASS PROGRAM

Beginning in the early 1970's, with the Arab oil embargo and rapidly increasing energy costs, national interest in the development of alternative energy sources began to develop. One technology which received renewed emphasis in response to the "energy crisis" was wood energy. Firewood, and cogeneration technology, two already developed uses of wood for energy, received new emphasis.

Firewood was the primary source of man's energy prior to the 1900's, and still is the principal source of energy for much of the world's population. The burning of wood residue to produce electricity and process steam (cogeneration) has been a standard technology in the forest products industry for much of the last 30 years. The use of firewood for the home market, and the interest in cogeneration increased markedly in the mid-1970's. Fortunately there was a rich literature to refer to in initiating the UC program in biomass production. In the 50s and 60s the paper industries sponsored research worldwide on short rotation, intensively managed plantations; reported 3-10 fold increases in yield over conventionally managed forests were common. Improved seed and clonal outplanting stock, particularly of hardwood species (including poplars, willows, and eucalypts), were used routinely in such plantations and were available for testing in California. Turn-of-the-century, privately owned eucalyptus plantations in California, and some USDA and industry-sponsored programs with eucalyptus and other hardwoods begun in the early 60s, made it abundantly clear that wood fiber production in California could be increased dramatically by intensive culture of improved hardwood species, with particular emphasis on eucalyptus. Biomass projects were officially funded at UC institutions in the early 70s.

The UC's Landscape Tree Evaluation (LTE) program, begun in the early 60s, also helped get the program going relatively rapidly. The objective of LTE was to evaluate a wide range of native and exotic trees for their use in landscape plantings in a variety of planting sites and report on their overall growth rate and form. LTE required a collaborative effort on the part of Farm Advisors and Specialists and Agricultural Experiment Station faculty members; as a consequence the identification of some fast-growing tree species in the eucalyptus, pine, casuarina, and poplar genera, that were also adaptable to marginal planting conditions, were revealed to a research group accustomed to working together. Given the impetus of the energy crisis, a UC biomass team was formed relatively rapidly from this LTE nucleus.

As ranchers, forest landowners, and owners of small rural properties began to come to Cooperative Extension in the mid to late 1970's with questions about planting trees to produce energy crops, predominantly firewood, personnel with LTE experience were called upon to give answers. The LTE program had identified major gaps in what was known about the management of trees, in general, not only for energy production. Interest in tree planting escalated when growers heard claims, often unsubstantiated, of extremely high growth rates, especially with eucalyptus. This led to the establishment of research plots in several counties and at UC Agricultural Field

[1]Presented at the Symposium on Multiple-Use Management of California's Hardwood Resources, November 12-14, 1986, San Luis Obispo, California.

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Stations to give local growers a better idea of what species would grow on different sites, what management practices were necessary, and what range of growth rates could be expected.

COORDINATED U.C. EFFORTS IN BIOMASS

As clientele interest in planting biomass species increased, and research gaps became increasingly glaring, Cooperative Extension and Agricultural Experiment Station researchers formally organized the Biomass Working Group in 1982 to address problems involved in the growth, management, harvest, and marketing of tree species for biomass. Initial priorities for the Group focused on:

(1) Identifying data on biomass production;

(2) Identifying information gaps;

(3) Developing standardized procedures for developing new research-based information;

(4) Addressing claims of super growth;

In order to determine the state of our knowledge about biomass production, and especially eucalyptus production, Cooperative Extension, together with the USDA Forest Service's Pacific Southwest Forest and Range Experiment Station, organized the Eucalyptus Symposium in Sacramento in June of 1983. This brought researchers involved in eucalyptus production from throughout the state, nation, and with international contributions as well. The symposium helped bring our knowledge about eucalyptus and biomass production in the state up to date, it provided the opportunity to see how other countries organized their research and extension efforts to address their problems in biomass production and it identified the various industry, agency, and landowner organizations with an interest in biomass production (Standiford and Ledig, 1984).

As a result of this widespread interest in eucalyptus and biomass production, U.C. Cooperative Extension, in its role as a coordinator and facilitator of information exchange, worked with the California Department of Forestry to organize a cooperative group of interested parties, as a part of the California Tree Improvement Association. This group, now known as the Eucalyptus Improvement Association, has established goals and by-laws which gives it the potential to influence the rate of development of eucalyptus-derived biomass in California. Cooperative Extension assisted in development of an initial membership list, which led to a statewide membership of 683, representing over 2190 acres of land planted in eucalyptus in the state. The Biomass Workgroup has worked closely with the Eucalyptus Improvement Association since its inception. Currently, the Workgroup is composed of 27 individuals with backgrounds in forestry and forest products, horticulture, engineering, agricultural economics, agronomy, weed science, and range management.
Following the Eucalyptus Symposium, and after input from the newly formed Eucalyptus Improvem Association, the Biomass Workgroup was able to refine and give priorities to its list of goals The highest priority items identified were:

(1) Determine per acre growth rates for various species for different levels of management input, for different regions and climatic areas in the state;

(2) Evaluate the economic factors of production to provide growers with an assessment of the management potential in different areas of the state;

(3) Develop genetically improved sources of the most promising species/seed sources.

RESULTS OF COORDINATED EFFORTS

As a result of a team oriented workgroup approach, considerable headway has been made in achieving some of the goals listed above. Some of the accomplishments of the Biomass Workgroup to date include:

(1) Development of a cost of production data base for use in assisting potential growers (Klonsky, 1983).

(2) Development of a model to optimize financial returns or biological production from a eucalyptus operation, based on initial tree density and rotation length, using site information and economic data as inputs. This model is available to growers, or through the County Extension offices on microcomputer (Rinehart and Standiford, 1984).

(3) Standardization of planting design and data collection procedures (based on early experiences with biomass yield trials).

(4) Establishment of 18 field trials in 12 counties in the state, investigating over 13 different species, seed sources or clones.

(5) Lists of nurseries supplying biomass tree species; lists supplied to each county office (Donaldson, 1985).

(6) Development of recommendations for species and cultural practices assembled in a "How To" publication (Standiford, Donaldson and Breece, 1984).

(7) Lists of harvesting equipment for biomass operations, as well as lists for cogeneration facilities.

(8) Organization of local grower meetings and tours, reaching over 1000 growers and potential growers in 1983 alone.

(9) Development of clonal propagation methods with several species (Sachs et al. 1984).

(10) Development of slide tape on how to grow your own fuelwood (in cooperation with the International Tree Crops Institute); available through U.C.'s audiovisual library, used in presentations to several hundred prospective growers.

Based on a survey of nurseries supplying eucalyptus and other biomass species, it is estimated that in 1984, one million seedlings were planted on 1000 acres throughout the state (LeBlanc, 1985). Some of the accomplishments that coordinated research have had on changing grower behavior are:

(1) Yield plots and growth modelling show that growth ranges from 6 tons per acre per year on marginal sites with little management to over 30 tons per acre per year on high quality, intensively managed sites (3 to 15 cords per acre per year). Table 1 shows a list of U.C. Field plots, and summarizes current yield data. This research-based information, which has been distributed at grower meetings and in publications, has virtually eliminated the overly-inflated growth estimates that existed in the industry in previous years, and has given potential growers a more realistic estimate of growth.

(2) Nursery stock used to be supplied in a variety of container types, resulting in seedlings with varied physiological condition for outplanting. Seedlings are now routinely supplied in containers allowing for well-developed root systems, at least partially a result of research on nursery propagation at U.C.

(3) Research developed by the U.S. Forest Service on seed source performance has resulted in more attention to seed source by nurseries and growers. The provenance of a tree is now routinely specified when ordering seedlings, thereby improving the match of a seedling to a given growing site.

(4) Clonal propagation of eucalypts has been greatly advanced. Several promising eucalyptus clones have been identified released to private nurseries. Improved clonal propagation techniques have been passed along to several nurseries.

(5) There has been an increase in support of projects by growers and other state organizations, leading to more field projects throughout the state.

(6) Preliminary data from spacing trials, and results from computer simulation, has resulted in adoption of a tree density standard for biomass production of 25 to 50 square feet of growing space per tree (5' x 5' to 7' x 7'). Previous industry information suggested densities of as close as 15 square feet of growing space per tree (3' x 5'). These new standards means less capital outlay by landowers [sic] for trees, more trees available for planting additional acres, and little if no decline in total per acre yields. Planting design trials, to include densities similar to those above but with different between and within row spacing, are continuing.

(7) The importance of weed control and irrigation in the first two years after planting has been demonstrated, and is now routinely practiced in new plantings, therby [sic] greatly increasing survival (by as much as 80%).

FUTURE BIOMASS ACTIVITIES

There is a well-established clientele of individuals interested in growing trees as an energy crop in the state. It is anticipated that this area will continue to be important in the future, especially if energy costs increase as projected. The number of cogeneration facilities in the state is expected to double in the next 5 years, based on the number of license applications currently pending. In addition, several forest products companies are currently purchasing chips for use in paper manufacturing. This new and expanding market would give growers of biomass more flexibility in marketing. Work is expected in the 7 areas below in the next 5 to 10 years.

Genetic Improvement

Cooperative projects with the Eucalyptus Improvement Association have been developed, and are awaiting funding. Selection of superior trees of promising species are needed for use in provenance testing and seed orchard establishment. In addition, clonal propagation of superior trees would be carried out for furthur [sic] testing. Selections would take place in plantings throughout the state, with cold and salinity tolerance, growth rate and form as key criteria for selection.

Management Practices

Production functions are needed for cultural practices such as irrigation and fertilization on different sites in order to make better recommendations on the optimum management input for different sites.

Furthur [sic] Species/Seed Source Evaluation

Existing field plantings do not cover all potential planting areas in the state. Expansion of field plots to cover new areas will take place, and inclusion of new plant materials in future and existing field plantings will be evaluated.

Table 1. Summary of Woody Biomass field trials conducted by the University of California

County	Proj #	Leader	Year Estab	Year Measured	Species (Clone)	Density (trees/a)	Irr/ Fert	Yield* tons/acre/yr.
1 Solano	3608	Miller	83		E. cam. (C2)	2719	Yes/Yes	33 (est)
2 Solano	3608	Sachs	79	81	Ailanthus altissim	5000	Yes/Yes	13 (max)
					Acacia melanoxylon	(3x3)	Yes/Yes	13.4 (max)
					Salix babylonica	5000	Yes/Yes	15.1 (max)
					E. camaldulensis	5000	Yes/Yes	20.3 (max)
					E. cam x rudis	5000	Yes/Yes	16.9 (max)
					"Fry" poplar	5000	Yes/Yes	6.8 (max)
3 Solano	3608	Sachs	81	83	E. cam x rudis (CR-1 and CR-2)	1714 (5x5)	Yes/Yes	16 (avg)
4 Solano	3608	Sachs	83	85	E. cam. (C-1,C-2)	1936	Yes/Yes	13.2 (est)
						1452	Yes/Yes	16.3 (est)
						1162	Yes/Yes	13.7 (est)
						871	Yes/Yes	13.6 (est)
						830	Yes/Yes	13 (est)
						622	Yes/Yes	13 (est)
5 Orange	3608	Sachs	76	78	E. grandis, seedl.	11000	Yes/Yes	6.2 (avg)
				79	(harvested at 6	ca 10000	Yes/Yes	8.3 (avg)
				80	mo intervals)	ca 10000	Yes/Yes	9.7 (avg)
				81	E. grandis, above plots thinned (no border)	1900	Yes/Yes	39 (total plot)
6 Orange	3608	Sachs	82	85	E. grandis, seedl. (from Florida)	1714	Yes/Yes	13.7 (avg)
7 San Mateo		Costello	81	--	E. globulus	Coppice	No/No	----
8 Napa		Donaldson	79	81	E. camaldulensis	1740	Yes/No	1.7
			79	81	E. dalrympleana	1740	Yes/No	.5
			79	83	E. camaldulensis	1740	Yes/No	8.8
			79	83	E. dalrympleana	1740	Yes/No	4.8
			79	85	E. camaldulensis	1740	Yes/Yes	20.2
			79	85	E. dalrympleana	1740	Yes/Yes	7.3
9 Napa		Donaldson	77	81	E. camaldulensis	680	Yes/No	2.0
			78	81	E. viminalis	680	Yes/No	1.9
			77	83	E. camaldulensis	680	No/No	4.0
			78	83	E. viminalis	680	No/No	7.0
10 Napa		Donaldson	83		E. viminalis	870	Yes/No	---
					E viminalis	870	No/No	---
11 Riv.		Cockerham	82	85	E. camaldulensis	302-907	Yes/No	2.3 - 5.7
12 San Joaquin		Hickman	86	--	E. grandis	1210-1815	Yes/No	---
					E. cam. (C2)	1210	Yes/No	---

continued

Table 1. Summary of Woody Biomass field trials conducted by the University of California (continued)

County	Proj Leader #	Year Estab	Year Measured	Species (Clone)	Density (trees/a)	Irr/ Fert	Ave. DBH(in)	Ave. Ht(ft)
13 Yuba	Hasey	84	85	E. globulus	1210	Yes/Yes	2.45	25.6
		84	85	E. camaldulensis	1210	Yes/Yes	2.21	19.5
		84	85	C-1 clone	1210	Yes/Yes	1.65	15.8
		84	85	C-2 clone	1210	Yes/Yes	2.16	22.6
		84	85	E. viminalis	1210	Yes/Yes	1.79	17.9
		84	85	E. dalrympleana	1210	Yes/Yes	1.80	17.6
		84	85	Poplar hybrid	1210	Yes/Yes	1.82	20.4
14 Imperial	Mayberry	82	85	E. camaldulensis	907	Yes/Yes	4.00	27.5
		83	85	E. camaldulensis	1210	Yes/Yes	3.50	22.5
15 San Luis Obispo	Weitkamp	86	--	E. camaldulensis	680	No/No		
		86	--	E. viminalis	680	No/No		
		86	--	E. sideroxylon	680	No/No		

*Assumes 85 cubic feet/cord, 2 dry tons/cord

Coppice Management

One coppice management is currently underway. As new plantings reach maturity and are harvested, trials investigating different coppice management strategies will be necessary.

Harvesting Technology

There is currently a great deal of information on biomass harvesting, predominantly oriented to large ownerships. Technologies for small plantings, as well as a list of contractors who provide biomass harvesting services, are needed.

Market Development

Identification of future markets, as well as a mechanism for comparing prices for different products (i.e., firewood, delivered logs, delivered chips, sale of stumpage, etc.) will become increasingly important as more market outlets come on line.

Biomass Conversion

Evaluation of existing burners, for efficiency, emissions, and cost, as well as design of improved burners is necessary, in order that the maximum possible capture of energy is obtained, and reliable information is available for prospective buyers.

U.C. became involved in biomass research and extension in response to the social demand for alternative energy sources, and grower demand for alternative cash crops. Great strides have been made in making recommendations about feasible management systems, however more work is anticipated in the future. A multi-disciplinary team approach has proven successful in solving key problems with a major impact on this developing crop in a very short time.

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Central California Oak Residue Utilization and Marketing: Better Hardwood Management from Improved Utilization[1]

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Abstract: Limited information and observations indicate that there are some significant amounts of hardwood residue resources now available in the Central Coast area. Experience gained from managing and marketing eastern hardwoods is considered as our basis for dealing with western hardwood problems.

Inventory of the oak resource is discussed as a preliminary requirement for management. In addition, hardwood marketing, research and extension needs are also considered.

Evidence indicates that western hardwood use will be improved by better funded programs of research and extension in residue utilization and marketing. Improved hardwood utilization will yield both direct and indirect benefits. Direct benefits include additional, better quality wood at lower consumer cost and increased tax receipts. Other, indirect benefits include improved hardwood forest management, better fire management, and improved multiple resource management for watershed, range and recreation values.

Throughout the natural range of California oaks (Quercus spp. and Lithocarpus spp.), there is growing concern about the question of over-cutting and under-utilization. During the past few years, greater attention has been given to the problem of oak regeneration growth. However, oak utilization and particularly residue use is far less clear.

The Board of Forestry on the occasion of its Centennial anniversary sought to find new ways to approach forestry in California. It was reported at the Centennial II Conference (California Board of Forestry, 1985) that:

> Within California, both the timber and range-livestock industries are suffering. Both have prolonged periods of low product prices and major readjustment among producers. A number of ranchers have lost their property to foreclosure. Several of the major timber producers have been absorbed as part of leveraged buy-outs from investors without any historical interest in timber growing in California. In addition, a number of smaller landowners and loggers have either gone out of business or have had to limit their operations. Events such as these raise serious questions about the ability to attract and maintain private investment capital in the traditional resource industries such as timber and ranching. This is compounded by the negative perception that investment in forestry in California will be burdened with increasingly expensive regulations.

One of the major issues facing the citizens and land managers of California (identified at the California Centennial II Conference-California State Board of Forestry, 1985) is: "How can California forest and rangeland owners and industries better market existing and new products?" Several strategies have been identified including: 1.) research and develop new products (e.g., furniture, panels, pre-fab products) to meet identified demand; 2.) improve utilization of California timber species; 3.) develop active marketing associations for export of forest and range products; 4.) set up production teams to brainstorm, Identify innovative programs, and analyze current and potential markets; 5.) improve marketing techniques to increase demand through advertising and other techniques. Other strategies have been identified, but the above directly apply to the issue of extending utilizaiton [sic] the California hardwood resource. It is our contention that better land management will occur on California's hardwood lands through better utilization. Ranchers, for example, would approach hardwood land as areas to be managed rather than converted to grasslands given a better economic picture through integrated multiple use management (e.g., wildlife, range, hardwood utilization).

The purpose of this paper is to explore non-traditional approaches to multiple use management of the hardwood lands in Central California. Traditionally, the full value of California's oak and hardwood resources has not been widely recognized. Until the late 1950's, oak was a major material that supported the sizable Central Coast charcoal business. More recently, since the Arab Oil Embargo in the early 1970's, the California oak resource has again been recognized as an important fuelwood resource. However, aside from this wood energy use, only a very limited use has been made of the California oak resource. A few sawmills now manufacture a limited amount of oak lumber, and oaks have

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been used for other products like pallets, posts, and ties on a restricted basis. This paper will discuss some alternatives for better management, utilization and marketing of California's oak resource.

EASTERN HARDWOODS

In sharp contrast to this picture of under-utilization of California oaks, the hardwood resource in the northeastern United States has undergone, in recent years, a kind of "economic renaissance." For many years, the rate of hardwood utilization in the northeast declined steadily. This decline was due primarily to a decrease in wood quality- which included an increase in small sized, poorly formed and defective stems. As a result of the increasing quantity of this low quality hardwood material- many speciality [sic] mills in the northeast were forced out of business and competition for the lucrative export market became extremely difficult. This increasing problem of low quality hardwood growing stock was exasperated by the increased ac-cumulation of hardwood residues.

In the late 1970's, local demand for eastern hardwoods as a wood energy raw material source and for wood pellets increased significantly. However, the most significant improvement in northeastern hardwood utilization resulted from the development of new, engineered panel products These new particleboard products. called wafer board, and oriented strand board (OSB) are products that can be made from relatively low quality hardwood raw materials. As a result, these new wafer board mills and the 0SB plant which opened in 1981 at Clardon, New Hampshire, had a very significant impact on utilization of low quality northeastern hardwoods.

The northeastern hardwood business has faced many of the same problems now facing the California hardwood industry. Of course, the northeastern industry is a much older business which is well established with a unique marketing system. Through a complex matrix of hardwood trade associations (see Appendix) the eastern hardwood marketing system includes a relatively strong technology transfer process. It is interesting to note that most of these associations are located in the eastern and midwest areas of the United States. Presently, there is only one major west coast hardwood association.

The technology transfer segment is a joint system where the wood industry, together with state and federal agencies, such as the State Utilization and Marketing Forester as well as the Cooperative Extension Service, have developed a system to connect the university and state research laboratories with the technology user at the plant level. Of course, this system is a "two way" pipeline which not only moves information from the lab to the user, but also provides a mechanism by which field problems are transmitted to the laboratory for appropriate solutions. Timely applications is one of the most significant aspects of this technology transfer process. In a relatively short time, the over-supply problem of low quality eastern hardwoods was identified. and practical solutions were developed and implemented. on a timely basis.

New technology and technology transfer alone will not solve the California hardwood problems. However some of the techniques used to deal with the northeastern hardwood problem may, in fact, have application to the western oak utilization problem.

WESTERN HARDWOODS

A number of problems relating to the utilization of California's hardwood resource have been identified. Some of the major western hardwood management problems focus on: 1.) inventory techniques; 2.) lumber drying and machining techniques; 3.) volume and biomass (both total and available); 4.) multiple use management (e.g., range, wildlife, recreation, watershed) interaction with wood value; 5.) residue utilization; and 6.) hardwood marketing. Other researchers and managers have earlier addressed some of these problem areas, in at least a preliminary investigation. For example, the California Forest Products Laboratory has carried out a number of drying, machining, and a variety of other wood property evaluation tests of several California hardwoods. In addition, the California Cooperative Extension Service during this past year has published a management guide for multiple use management of oak woodland for wildlife, range and wood resources.

However, the question of residue utilization and marketing are two western hardwood problem areas that have not been widely addressed. For this reason, it is now timely to consider these two problem areas more closely. In terms of hardwood residue utilization, there are still many unanswered questions, such as:

1. What is the volume of residues on hardwood lands?
2. What types of products could be manufactured from these residues?
3. What can be done to better organize the very fragmented fuelwood market?
4. What Is the significance of oak residue in terms of: soil nutrients; fire hazards; aesthetics; restricted access; regeneration shade and shelter; Insect and disease; air pollution-disposal; additional fiber source?

These and many more questions remain to be answered. The remainder of this paper will focus on a research approach to identify ways to extend the utilization of hardwood (oak) residues.

OAK RESIDUE RESOURCES

At present, there are some reliable oak volume tables available that will permit satisfactory estimates of oak growing stock. However, there is very little information available now that will help a landowner determine volume and value of oak residue. For purposes of this paper, oak residue has been defined as including the total biomass material of the tree and stand that has not been conventionally utilized (e.g., bole for lumber, fuelwood products).

On any walk through an oak stand, it is clear that total wood volume must include not only the live growing stock, but also the dead and down residue materials. For this reason, a "standard" cruise over an oak forest area will yield only a partial estimate of the total biomass volume. Total volume is a composite of both live, upright, and dead, down, materials. In many stands, depending on age and general condition, there is a very significant volume of raw materials in the residue category.

Biomass cruising techniques to estimate northeastern hardwood residue volumes have been developed and refined over the past twenty years. These biomass cruising techniques, which have been very effective, represent the first step in more efficient hardwood utilization.

An effective system of oak biomass/residue inventory could be based on the following procedures:

1. Field sample residues on a known area.

    a. These initial procedures would involve measurement and weight of oak residue in a clearly defined stand.
    b. Stands sampled could be correlated with stand density and volume.

2. On low altitude air photos of the study area, establish relationships between live crown diameter and residue volume.

3. On other appropriate study areas, field test these biomass/residue cruise techniques.

4. Develop and implement an appropriate technology transfer effort.

The initial phase of a residue inventory will be a field sample to determine both volume and condition of the residue material. On a series of one-half acre sample plots identified from low altitude air photos, a full sample of oak residue will be measured and correlated with individual tree size and crown diameter. These residue volume measurements will be based on direct volume measurement of larger pieces and direct biomass weight of smaller materials. In addition, the condition of all residues, in terms of soundness, will also be noted and a moisture content sample taken from different size materials for lab analysis.

The second phase of an oak residue resource inventory would be construction of residue tables to crown diameter. "These residue tables will then be field tested, using low altitude air photos and "ground truth" test plots. Results of these field tests will provide a measure of the accuracy with which it is possible to predict the volume of oak residues based on air photo, biomass cruising techniques.

If these oak residue, biomass inventory techniques are indeed effective, the final step of the project will be to develop an effective technology transfer system. Information and details about collecting oak residue field information will be provided to interested individuals and groups throughout the state in a timely systematic process. This technology transfer effort will be the first step towards better utilization of this important oak residue resource. Beyond this point of oak residue resource inventory and technology transfer process lies the very important element of a marketing strategy.

RESEARCH NEEDS

Improved residue utilization is only a small part of a much larger utilization [sic] problem of California hardwoods. A fractured market, at best, exists for the sale of hardwood products (e.g., fuelwood, lumber, and specialty products). This market picture would be improved with: 1.) execution of research on more effective ways of utilizing and marketing the California hardwood resource; 2.) formation of trade associations or cooperatives focused on management and utilization of California hardwoods (similar to the effort put forward by the California Redwood Association to find available markets for coast redwood); and 3.) development of landowner assistance programs.

Leadership is the key to improving the under-utilization and land management problems of California's hardwood lands. Technical trade associations and/or land owner cooperatives along with the California Board of Forestry could play a key role in responding to the Centennial question "How can California forest and rangeland owners and industries better market existing and new products?"

SUMMARY AND CONCLUSIONS

At present, there is in California a large and valuable hardwood resource that suffers from limited management and utilization. In recent years, similar problems in connection with eastern hardwoods have been identified, and solutions developed. One method that can improve western oak utilization is to extend the use of residues. However, more efficient residue utilization must be preceded by a stronger hardwood research and market development program.

A more efficient hardwood marketing process can be constructed on the following strategies: 1.) extend hardwood association activity; 2.) develop active hardwood landowner and marketing cooperatives; and 3.) more aggressive national and international sale promotion program.

A complete residue utilization program must include a strong research component. Some of the major residue use questions include: 1.) residue volume, total and available; 2.) inventory techniques and costs; 3.) new residue and solid wood products; 4.) residue harvest, techniques and cost; 5.) effect of residue use on other multiple use, oak resource values. In order to investigate these residue use and marketing questions, it is essential that an adequate and continuing funding source be provided. At present, there is a great need for more fundamental data on hardwood resources.

Improved hardwood utilization will require an expanded technology transfer effort. It is encouraging to note that just recently, the California Cooperative Extension Service, in cooperation with the California Department of Forestry, has funded several extension specialists to provide information about the hardwood resource. This is a good start, bur additional technology transfer is still needed for a complete, efficient hardwood information program.

Improved hardwood utilization will require expanded program efforts and funding support in terms of: 1.) residue utilization, 2.) hardwood marketing and 3.) hardwood information transfer. Better hardwood utilization is the basis for improved forest resource management, on a sustained yield, multiple use basis. Improved utilization and management will provide forest landowners with additional alternatives to the current practice of woodland conversion. In addition, improved management and utilization also offers other public benefits in terms of: 1.) more wood at a lower cost; 2.) improved tax receipts; 3.) improved visual quality and 4.) improved recreational opportunities. Hardwood utilization and management is today in California a pressing issue that requires a responsible and timely resolution effort by both the private and public sectors. Improved multiple use land management of California's hardwood lands can occur with better utilization and product marketing.

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APPENDIX

Partial List of Important Domestic Hardwood Associations

1. National Wood Pallet and Container Association
2. Associated Cooperage Industries of America, Inc.
3. Hardwood Dimension Manufacturers Association
4. Southern Hardwood Square Association
5. Maple Flooring Manufacturing Association
6. National Oak Flooring Manufacturers Association
7. Hardwood Research Council
8. Maine Hardwood Association
9. National Association of Furniture Manufacturers
10. Furniture Manufacturers Association of Calif.
11. Hickory Handle Association
12. Appalachian Hardwood Manufacturers, Inc.
13. The Hardwood Institute
14. National Hardwood Lumber Association
15. Indiana Hardwood Lumberman's Association
16. Northern Hardwood and Pine Manufacturers Assoc.
17. Southern Hardwood Lumber Manufacturers Assoc.
18. Southern Hardwood Manufacturers Club
19. Wood Turners and Shapers Association
20. Fine Hardwoods-American Walnut Association
21. Hardwood Plywood Manufacturers Association
22. Hardwood Veneer Association, Inc.

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An Agroforestry System for California and Other Semi-Arid Mediterranean Areas[1]

Nancy K. Diamond[2]

Abstract: The purpose of this study was to describe the use, status and land use problems of semi-arid mediterranean lands worldwide and to suggest an appropriate agroforestry system. Experimental design and management recommendations for a proposed set of preliminary species/spacing trials and also two long-term demonstration projects were presented for two marginal rangeland sites in California's Central Coast region (San Luis Obispo County). Additionally, recommendations for the potential transfer of the California system were then made on the basis of information on the biological and physical characteristics and agroforestry research capacity of the semi-arid mediterranean areas.

To begin to understand the potential of agroforestry for California's hardwood lands, it is important to first gain an overview of land use in the entire semi-arid mediterranean geographic zone (hereafter referred to as the SAM Zone). Located primarily on the west coasts of continents, from approximately 30 to 45 degrees North latitude to 30 to 35 degrees South latitude, and receiving winter rainfall, SAM areas can be found in California, the countries in Europe, North Africa and the Middle East which surround the Mediterranean Sea, central Chile, southwestern South Africa, and three areas in Australia (the southwest corner of West Australia, the southern portion of South Australia, and the western half of the Victoria District) (Rumney 1968). Despite its limited size, the SAM Zone has had a strong influence throughout history on the economic and cultural development of adjacent humid and arid regions.

SAM areas have provided livestock range, cropland and fuelwood resources and have also accomodated [sic] both sedentary and migratory human settlement from adjacent areas. The demand for these products and amenities will increase in the future as population increases, yet the productivity of the SAM Zone has been reduced as a result of destructive land use practices such as over-grazing, over-cultivation and destruction of the woody plant species (Secretariat of the United Nations 1977). The many recent conferences and symposia (e.g. FAO 1976; Secretariat of the United Nations 1977) on land use and/or environmental degradation in the semi-arid areas have consistently recommended returning to selected traditional soil and water conservation measures, fallowing, intercropping and using drought-resistant species for wise stewardship of marginal dry lands. Other suggestions have promoted the use of new genetics technology to select or create plants with improved qualities such as drought-resistance, the ability to fix nitrogen, produce fodder, and/or grow in combination with other plants.

Agroforestry systems for the SAM Zone can incorporate many of these suggestions and could potentially provide food and energy in an ecologically-sound manner. As defined by Combe and Budowski (1979), agroforestry is:

> A group of land use management techniques implying the combination of forest trees with crops, or with domestic animals, or both. The combination may be either simultaneous or staggered in time and space. The goal is to optimize per unit of area of production whilst at the same time respecting the principal of sustained yield.

Incorporating the above concepts, a plan was developed for an agroforestry system suitable for use in the Central Coast region (San Luis Obispo County) of California's SAM Zone. The methodology of the International Council for Research in Agroforestry (ICRAF 1982) was followed. The plan for this system also includes an assessment of the potential for technology transfer since the geographically-separate areas of the SAM Zone have uniquely similar physical, ecological and land use characteristics. This assessment, based on a review of the research needs and limitations of other SAM areas (Australia, Chile, Greece, Israel, Morocco and Spain), was used to modify the recommendations made for the California system (Diamond 1987).

LAND USE IN THE CENTRAL COAST REGION OF CALIFORNIA

Grazing and dryfarming have been the predominant land use in the Central Coast region of California. A variety of horticultural crops, including walnuts, almonds, grapes, avocados and citrus have been grown successfully with and without irrigation. Since the early 1900's, tree plantations have been established which

[1]Presented at the Symposium on Multiple-Use Management of California's Hardwood Resources, November 12-14, 1986, San Luis Obispo, California.

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incorporate eucalypts, pine and miscellaneous conifer species to provide shelter, fuelwood and other forest products such as Christmas trees. Native oaks have historically provided mast (acorns for livestock feed), fodder, shade, charcoal and firewood for residents of the area.

California's Central Coast is faced with many of the same economic pressures confronting other rural areas in the state. Subdivision of rangeland due to increasing urbanization, and a poor livestock market, have resulted in frequent overstocking of livestock and increased levels of degradation of the grazing resources of hardwood lands. Additionally, the oaks are being increasingly harvested to improve forage quality and quantity, to provide fuelwood and income from both local and major urban markets, and to clear land for irrigated farms and residences. Although the harvesting of oaks has occurred in the past for all of the above-mentioned reasons (Rossi 1979), harvesting has increased over the last five to ten years as a result of economic trends such as decreasing economic returns from livestock, greatly expanded fuelwood markets since the 1973 "oil crisis", and increasing rural populations. Given the inconsistent regeneration of some oak species and the threat to wildlife habitat, these continuing pressures on oaks are cause for concern and could be alleviated by more intensive, sustainable and economically-diversified use of already-cleared hardwood lands. Other hardwood land resource problems include the increased statewide occurrence of salinization, alkalinization and the reduction of groundwater levels as irrigated acreage increases. Each of these problems reduces the profitability of irrigated farming, livestock and forestry systems in California.

EXAMPLES OF AGROFORESTRY SYSTEMS RELEVANT TO CALIFORNIA

Examples of agroforestry systems from the past and the present can provide guidance for the development of an appropriate agroforestry system for California. As mentioned previously, mast of native oaks was frequently used to fatten sizable herds of livestock, from the time of the Spanish missions and ranchos until the middle of this century. Both mast feeding and cutting of branches for forage was also particularly common during difficult economic times. The Spanish missionaries also introduced mixed farming systems developed in the European SAM Zone to California. These systems included a variety of agricultural crops, horticultural trees and shrubs, and cattle, sheep and/or swine. Presently, there are ranchers and farmers within California and specifically within San Luis Obispo County who are practicing different types of agroforestry. Combinations generally include woodlots of fast-growing fuelwood trees or grape vines on ranch land, or multiple species of fruit and nut trees grown together, sometimes with annual crops below. Other examples of mixed use found statewide include grazing of National Forests in some areas and tree windbreaks on farms and ranches.

Indigenous agroforestry systems are quite common in the Mediterranean Basin countries and include the mixed garden systems brought to California by the Spanish missionaries with managed species of both native and introduced trees, agricultural crops and livestock; the "cork and pork" (*dehesa*) system of managing native cork oaks (*Quercus suber*), forage species and swine in the Iberian Peninsula (Parsons 1962) and the extensive use of native shrub formations such as *maquis* and *garrigue* (similar to California's chaparral) for grazing by goats and sheep.

Use of planted tree and shrub fodder species is also prevalent in the SAM areas of Australia and Chile. In both of these countries, New Zealand-style agroforestry plantations of widely-spaced Monterey pine (*Pinus radiata*), pasture species and sheep are commonly found. Due to their typically small farm size, both Chileans and Greeks have planted intensive, mixed-use systems which combine many tree, crop and livestock combinations including fodder trees and shrubs. The native shrub formations are grazed by livestock in all of the SAM areas.

NEW TECHNOLOGIES FOR A SAM ZONE AGROFORESTRY SYSTEM

Relevant research from both within and outside the SAM Zone can be incorporated into the design of an agroforestry system appropriate for the SAM Zone. Researchers in Texas (Felker 1981), Southern California (Felker *et al*. 1982), Oregon (Gordon *et al.* 1979; Wollum and Youngberg 1964; Tarrant 1983), Hawaii (Brewbaker and Styles 1982; MacDicken and Brewbaker 1984), and Illinois (Funk *et al*. 1979) have provided valuable information on the characteristics, management and potential of nitrogen-fixing tree and shrubs. Research on biomass tree farms in California has been undertaken by Ayers (1984), Pillsbury and Williamson (1980), and Standiford *et al*. (1983). The characteristics and management of fodder trees and shrubs have been investigated extensively in Australia (Everist 1972) and North Africa (Le Houerou 1978, Ibrahim 1981). Management of forest grazing has been researched many areas, including California (Kosco and Bartolome 1983) and the Southeastern United States (Linnartz and Johnson 1984). Furthermore, detailed plans for the management of livestock and legume pastures under widely-spaced forest plantations in New Zealand (Hawke *et al*. 1983a, 1983b) have been modified and applied to Australian SAM Zone conditions (Howes and Rummery 1978).

DESIGN AND MANAGEMENT RECOMMENDATIONS FOR A CALIFORNIA AGROFORESTRY SYSTEM

Although agroforestry components will vary in different SAM areas to include species and varieties which meet local needs, the design and management of the basic agroforestry system planned will be the same. Institutional and technical support for agroforestry research is adequate in all six of the areas (Australia, Chile, Greece, Israel, Morocco, Spain) selected as potential sites for the transfer of California agroforestry technology. However, with the exception of California and Australia, the financial constraints of the target population of small farmers in Chile, Greece, Morocco and Spain may preclude extensive irrigation, heavy use of commercial fertilizers, and capital-intensive equipment and management. For these reasons as well as environmental concerns, the proposed agroforestry systems -- even in the United States -- should incorporate water and soil conservation methods, drought-resistant environmentally-adapted plants, and alternatives to commercial fertilizer (e.g. manure) whenever possible. Additionally, the successful technology transfer of the proposed demonstration projects demands that the scale of the demonstration project be similar in size to the average land holding in that country.

The first step will be a species and spacing trial to determine which plant species at which particular plant spacing exhibit the best survival and growth after three years when grown alone and in mixed species, interplanted plots. The effectiveness of the site preparation and other cultural practices will also be evaluated for application in the demonstration project. The plants species which will be included in the proposed San Luis Obispo County trials were selected because of their compatibility with local environmental conditions (climate, soils, elevation), social suitability (the products provided, management required, cultural preferences), satisfactory growth in previous local trials and availability. A randomized split-block design, which is appropriate for small areas, will be used to compare growth and survival of seedlings at three intra-row spacings, 0.6, 1.2, and 1.6 meters (2, 4 and 6 feet). A uniform distance of 3.6 meters (12 feet) between rows will allow for the use of typical California farm equipment such as tractor mowers. Edge effects will be minimized by a 3.75 meter border width of trees (Zavitkovski 1981, MacDicken and Brewbaker 1984).

The woody perennial components of this design concept will include fast-growing trees which are harvested on short-rotation cycles for fuelwood, fiber, timber and local products such as Christmas trees or nuts. These drought-tolerant woody species should be planted using dryland soil and water conservation methods such as contour ploughing, micro-catchments and minimum tillage. Two species of eucalyptus which are indigenous to the SAM Zone, *Eucalyptus camaldulensis* Dehnh. (river red gum), and *E. viminalis* Labill. (manna gum) will be included in the agroforestry trials to provide fuelwood, fiber and timber. Two pine species which are also indigenous to the SAM Zone, *Pinus halepensis* Miller (Aleppo pine) and *P. eldarica* (Eldarica pine) will be intercropped with the eucalypts and also nitrogen-fixing fodder shrubs and will produce Christmas trees, fuelwood, fiber or timber. Both indigenous and exotic nitrogen-fixing woody species, will serve as long-term nurse crops for the pines and eucalypts and will produce fodder (and also fuelwood). In the San Luis Obispo County system, species trials tested will include *Acacia saligna* (Labill.) H. Wendl (willow acacia), *Ceanothus cuneatus* (Hook.) Nutt. (wild lilac), *Ceanothus sanguineus* Pursh. (red stem ceanothus), *Elaeagnus commutata* Berh. (silverberry), and *E. umbellata* Thunb. (autumn olive).

The agricultural components of the system will be both annual and perennial forages, including some species which fix nitrogen. *Hordeum vulgare* L. (barley) and *Trifolium subterraneum* L. (subterranean clover) will be planted in the San Luis Obispo County agroforestry system. The livestock component of these systems will be either cattle, sheep or goats, depending on which animal is traditionally used in each specific SAM Zone area. For the two San Luis Obispo Country trial sites, beef cattle will be used at the Cal Poly site and St. Croix sheep will be present at the San Miguel site.

Site preparation, seedling establishment and cultural practices will be the same for the species screening and the demonstration project. Weed control, by means of deep ripping, heavy grazing, mowing or use of pre-emergent herbicides, is critical both prior to seedling establishment and also after planting. The latter two methods are appropriate at regular intervals for one to two years after planting to decrease plant competition for resources and rodent populations. However, the use of pre-emergent herbicides may be appropriate only in areas with available technology and capital resources. Manual mowing and heavy grazing prior to planting, in addition to close initial spacing with thinning after seedling establishment, will be an appropriate method of weed control in most situations.

Planting at the beginning of the seasonal rainfall period (November-December) aids in establishment and allows for replanting and establishment in January or February, if necessary. Use of fertilizers at the time of planting has been shown to aid tree establishment and either a mixed nutrient, slow-release fertilizer tablets (*Agri-form*) or non-commercial fertilizers (e.g. manure) can be used (Ayers 1984). The need for a permanent irrigation system can be eliminated through the careful selection of plants which are drought-resistant and the use of soil and water conservation measures. However, supplementary irrigation should be applied monthly (or as needed) during at least the first, and possibly the second dry season after establishment. Fencing is necessary for one to two years after planting to exclude deer and rodents, and prevent livestock trespass. Predator perches and frequent weed control has helped to control rodent populations for the Cal Poly wood energy plantation in

San Luis Obispo County (Ayers 1984). Fencing and/or road establishment around the perimeter of the plantation, and frequent weed control will also help prevent fire damage.

Table 1 shows the management timeline for the 5-year preliminary species and spacing trials. Nine plant species (two eucalypts, two pines and five nitrogen-fixing fodder species) will be planted in December of Year 1 and 2 in monoculture plots at three spacings. Year 1 monoculture trials will be replicated in Year 1 and 2 to obtain additional growth and survival data. Each year, all plots will be replicated twice. Plantings from both years should provide a good estimate of the monoculture yields with which to standardize the yields attained for intercropping trials planted at the end of Year 2 (Mead and Stern 1980). The purpose of Year 1 and 2 trials is to determine which one of the eucalypt and pine species and which two nitrogen-fixing fodder shrubs exhibit the best survival and growth after two years of growth and at which spacing. Year 1 and 2 monoculture species plots will each have 108 plants (not including buffer plants) and each year, approximately 2,000 plants will be planted on 3.5 acres. Monocropped trials in Year 1 and Year 2 will each be removed 2 years after planting.

The purpose of Year 3 and 4 trials is to determine which of the two nitrogen-fixing fodder shrubs serves as the best nurse crop for the other two woody species (eucalypt and pine), and at what spacing. Each of the two nitrogen-fixing fodder species will be intercropped with the eucalypt and pine species in separate trials, using the three intra-row spacings used in monocrop trials in Year 1 and 2. A split-split randomized block design will be used with split plots for each nitrogen-fixing plant divided into three sub-plots for the three intra-row spacings. The nitrogen-fixing fodder species will be alternated within rows with eucalypts and pine (N-E-N-P-N-E-N). This arrangement should help to minimize potential allelopathic effects, if they should occur, of both the eucalypt and the pine species on the growth or nitrogen-fixation capabilities of the fodder species. Each set of trials in Year 3 and 4 (two replications and buffer rows) will cover 2.25 acres and include approximately 500 trees. Survival and growth measurements will be taken at three-month intervals during the first year of growth for single species and multiple species plantations, and at six-month intervals after the first year of growth. A brief weekly monitoring will be taken and project costs tallied annually.

All species and spacing trials will be removed in Year 5 and the demonstration project will be planted with the combination of nitrogen-fixing fodder species, eucalypt and pine trees which exhibited the best growth and survival. One-sixth of the total area will be planted each year with woody species and barley pasture, for six successive years, so as to provide a sustained yield of eucalyptus fuelwood and forage. By

Table 1. Management for Species and Spacing Trials

Month	Activity
October	Year 1 - Deep ripping (one-time only)
November	Weed Control
December	Dig holes; Plant with fertilizer tablets
January	Replant, as necessary; Weed control
February	
March	Weed control
April	
May	Water; Weed control
June	Water
July	Water; Weed control
August	Water
September	Water; Weed control
YEAR 1	Monocrop 1 is planted.
YEAR 2	Monocrop 2 is planted.
YEAR 3	Monocrop 1 is removed, Intercrop 1 is planted
YEAR 4	Monocrop 2 is removed, Intercrop 2 is planted.
Years 1-4:	
Monitoring:	Bi-monthly, for trial duration (five years)
Data collection (survival and growth):	At 3, 6, 9, 12, 18, and 24 months after planting.
YEAR 5	Intercrop 1 is removed at the beginning of the growing season and Intercrop 2 is removed at the end of the growing season. Planting begins for the intercropped demonstration project using the combination of spacing and plant species which showed the best survival and growth.

planting in this manner and restricting grazing until trees are 2-3 years old, rotational grazing can be practiced using proper fencing.

Eucalypts will be harvested for fuelwood in the spring of their sixth year of growth. Coppice management should be practiced thereafter, with subsequent cuttings occurring every 4-6 years until age 30. The pines will also be harvested at age six for Christmas trees or firewood. Alternatively, the pines could be allowed to continue growing, pruned and thinned to a spacing of 100 trees per acre (with excess trees being sold for firewood) and harvested for timber at 25-30 years of age. For either option, the pines will need to be replanted after cutting. The nitrogen-fixing plants will serve as dry season animal fodder and can be grazed directly or lopped for a cut-and-carry system after age 2 or 3 years.

Below the woody overstory, each section of barley pasture will provide a source of short-term income and cut-and-carry forage for the first two years. After this time period, the pasture will be converted to a sub-clover/barley mix to increase the available nitrogen in the agroforestry system and enhance livestock nutrition. Subclover should be planted at a rate of 10 to 20 pounds per acre with inoculum, just prior to, or during the first seasonal rains (November-December). Fertilization with phosphorus, potassium and sulfur is also recommended when available. The clover can be grazed as soon as the leaves develop (generally six months after planting), and animals should be removed when the soil surface and horizontal stems become visible. Therefore, approximately 2.5 years after tree and shrub establishment, closely-controlled direct grazing can be allowed with proper tree protection such as fencing and livestock repellants. The sale of livestock and their products can provide a new source of income to the system.

The variety of components in this system can potentially provide a number of sources of gross income. Preliminary best estimates were obtained for cost and return calculations using methods based on Australian and New Zealand economic analyses and information on the economics of California livestock, eucalyptus energy plantations and Christmas tree operations. It was assumed that the 18-acre site would be managed as either a cow-calf or sheep-ewe operation. Since herd sized are fairly small, animals would be bred annually by bringing in high-quality bulls or rams to the site and paying breeding costs. Economic calculations were based on a 1.2 x 3.7 meters (4 x 12 foot) plant spacing (900 woody plants per acre). All figures were calculated on a per-acre basis, for the 18-acre site. A discount rate of four percent was used, in addition to an investment period of seven years. It was assumed that the property was owned rather than rented and that all investment capital would be provided by the farmer-investor. Furthermore, it was also assumed that fencing, equipment and access roads were already available on the site. For these calculations, the land managers were assumed to possess the appropriate skills in livestock, pasture and woody species management. Additionally, only occasional outside labor would be hired for miscellaneous tasks.

Several additional assumptions were made about the San Luis Obispo County system's design, management and goals. The realistic target audience for this project are land owners and managers who have an off-farm source of income. Furthermore, these individuals will more than likely have other land use management goals such as ecological sustainability, economic diversification, stability and optimization (versus maximization) and self-sufficiencies for specific products (e.g. fuelwood) which may be as important to them as economic efficiency. These same caveats may also hold true for other SAM areas yet the system is also designed so that the choice of components and management intensity can be varied to fit other land use goals.

Using the microcomputer program, FORECON, the internal rate of return was calculated and used as the criteria for comparison of the two economic alternatives (cow-calf versus sheep-ewe operations). Both operations yielded a similar favorable return of 25 to 28 percent, if managed conservatively (low labor, time and capital requirements and used farm equipment), in addition to ecological and social benefits. Benchmark figures from Australia and New Zealand yielded somewhat lower returns, 7-13 percent, which may be the result of longer time frames (25-30 years) and the increased management costs from larger acreages and herd sizes (Ferguson and Reilly 1978, Bilbrough 1984).

CONCLUSIONS

Agroforestry can help to address the current needs of the hardwood rangelands of California, and other SAM areas, by producing a variety of goods in an intensive and sustainable manner which combines old and new technologies. Technology transfer of this system within the California SAM area can be accomplished by means of training sessions at the site for farmers, ranchers, land managers, extension agents and graduate students. Coordination of SAM zone trials is recommended and could be undertaken by the International Council for Research in Agroforestry.

One researcher, Dr. Michael Baumer, addressed the need for further research into the social, economic and political factors involved in the adoption of agroforestry systems:

> The problem is not to create agroforestry systems which will be suitable for application in Mediterranean iso-climatic region (olive trees and cereals exist there since several thousands of years, and many other agroforestry systems are typically Mediterranean, such as 'montado' in Portugal, 'dehesa' in Spain, caroob (sic)-tree/sheep breeding/cereals in Cyprus or in Israel, 'hema' in Syria, etc.). The real difficulty is to let an appropriate system be adopted (or adapted and re-adopted) by concerned populations. (emphasis added) (Baumer 1985)

Together with new technology and appropriate social, economic, and political support, these traditional systems offer the SAM Zone, in California and beyond, new hope for increased productivity.

Acknowledgements: I thank Pam Muick and Lee MacDonald, University of California, Berkeley, for their editorial comments on this paper.

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Relating Cordwood Production to Soil Series[1]

Dennis J. Lytle and Sherman J. Finch[2]

Abstract: Oak production data were gathered on 8 different soil series in support of soil surveys in Yuba and Sutter Counties, California. Cords per acre of blue oak (Q. douglasii) and interior live oak (Q. wislizenii) varied widely depending on past management, soil properties and climate. Soil properties that affected oak production were depth and available water capacity (AWC), presence of a "claypan" and type of underlying bedrock. Soil properties and their production and management limitations should be a consideration in hardwood management.

Oak production data is being included in National Cooperative Soil Surveys in California; principally because of its use for fuelwood, and because of the increasing importance and attention being paid to hardwoods. In this paper, data on cordwood volumes are reported for Yuba and Sutter Counties. Similar data are included in soil surveys in Lake, Mendocino, Sacramento and San Joaquin Counties.

DESCRIPTION OF THE STUDY AREAS

In Yuba County, the Blue oak-Digger pine forest cover type begins at about 38 m (125 feet) in the foothills of the Sierra Nevada mountains and extends to about 580 m (1900 feet) elevation. Figure 1 illustrates the relationships between elevation, moisture and the major vegetation types in Yuba County. The forest cover types are those described in "Forest Cover Types of the United States and Canada" (Eyre 1980).

We have further subdivided the Blue oak-Digger pine type into Blue oak-annual grass and Blue oak-interior live oak-annual grass. Digger pine (P. sabiniana) is a minor component in the blue oak types in Yuba County (table 1). Precipitation ranges from about 406 mm (18 inches) at the lowest elevations to about 890 mm (35 inches) at the highest elevations in the blue oak cover type (DWR 1966). Six soil series are mapped in the blue oak type in Yuba County (table 2). Depth to bedrock ranges from 25 to 64 cm (10 to 25 inches) or 50 to 100 cm (20 to 40 inches) depending on soil series. No soil series were mapped in the blue oak cover type that had bedrock at greater than 100 cm (40 inches). Underlying bedrock is metavolcanic (greenstone), amphibolite schist, granodiorite, or gabbro diorite (table 3).

In Sutter County, blue oak occur only on the north, east, and west aspects in the Sutter Buttes. Elevation ranges from about 23 to 640 m (75 to 2100 feet). Precipitation ranges from 432 to 483 mm (17 to 19 inches) (DWR 1970). Two soil series were mapped in the blue oak cover type in the Sutter Buttes (table 2). Depth to bedrock ranges from 25 to 50 cm (10 to 20 inches) or 50 to 100 cm (20 to 40 inches) depending on soil series. Underlying bedrock is andesitic lahar (mudflow) (table 3). Interior live oak was not found growing on these soils in Sutter County.

METHODS

The soil surveys in Yuba and Sutter Counties were made by five soil scientists, a forester, three range conservationists and a biologist from 1980 to 1986. As the surveys progressed, these scientists selected typical sites that represented the soil series, the overstory vegetation, and the understory vegetation. Table 1 lists the natural vegetation for each soil series phase in Yuba County. In soil surveys, vegetative production and species composition are used in the design and separation of soil series and soil mapping units. On forest land, changes in height over age, or site index, and changes in species composition are used by the soil scientist as one of the means to separate soil series and soil mapping units.

At 28 typical sites on 8 soil series, cordwood volumes for all trees were estimated. Cordwood volume was estimated by sample cruise or "zigzag" transect as used by the Soil Conservation Service (SCS). The procedure is defined in the SCS National Forestry Manual (SCS 1980). The process involved collecting data on 20 trees at each site. After heights and diameters were measured, cordwood volumes were determined from tables (Pillsbury and Stevens 1978). The volume data in table 3 represent observed volume not yield. Site index curves to determine yield were not available for blue oak, interior live oak or Digger pine at the time of our field work. Blue oak ages were obtained from 5 sites, but not in sufficient quantity to predict growth rates. For reference, the range in age was 86 to 125 years. These ages appear consistent with other studies (McClaren 1983, Neal 1980).

[1]Presented at the Symposium on Multiple-Use Management of California's Hardwood Resources, Nov. 12-14, 1986, San Luis Obispo, California.

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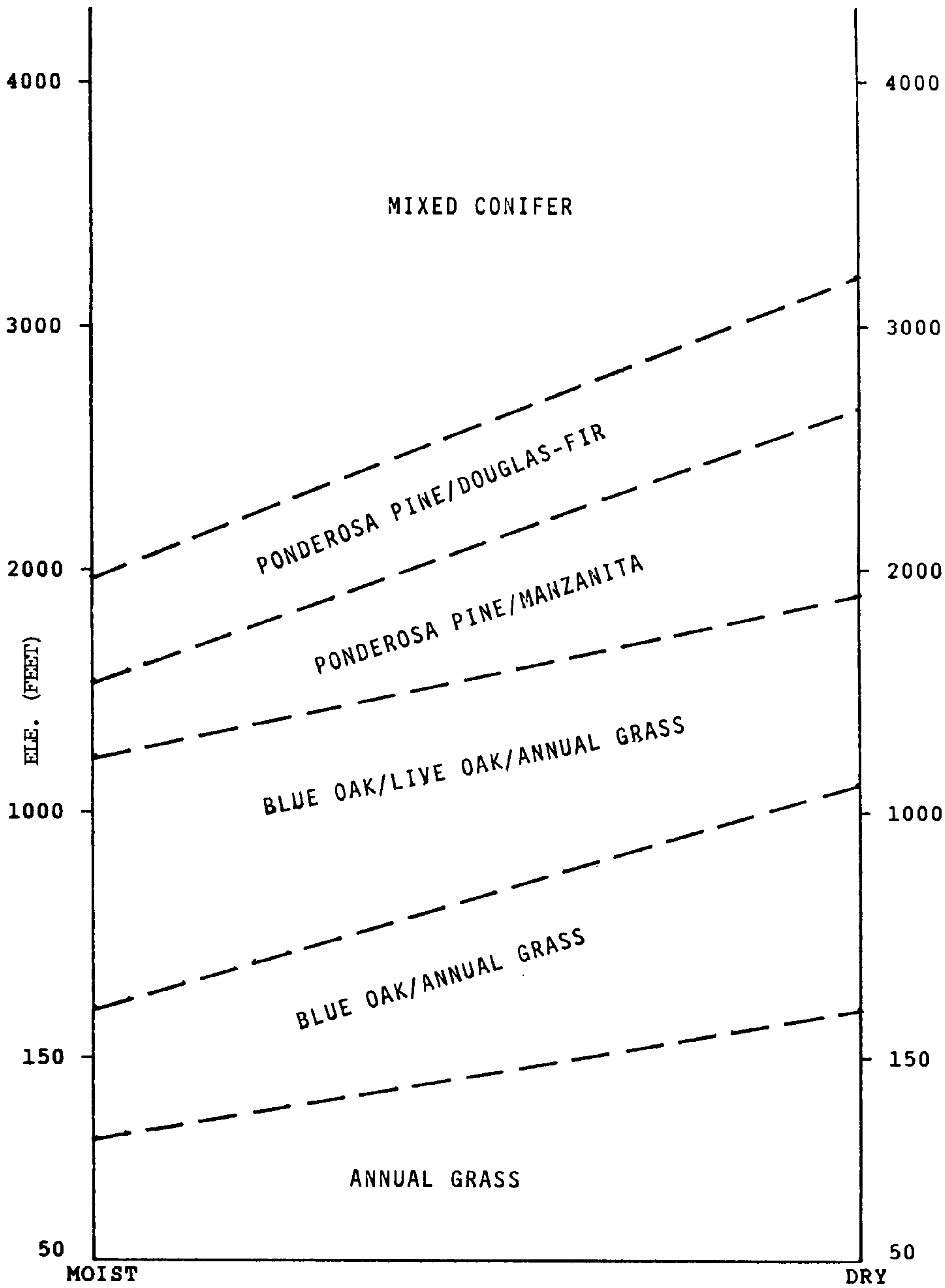

Figure 1--Schematic of vegetation, elevation and moisture in Yuba County, California.

Table 1--Natural Plant Communities

Soil Series Phase	Characteristic Vegetation		Percent Composition[1]	
	Common Name	Scientific Name	Dry Wt.	Canopy
Auburn loam	Blue oak	Quercus douglasii		40
	Soft chess	Bromus mollis	40	
	Wild oat	Avena fatua	10	
	Ripgut brome	Bromus diandrus	10	
	Rose clover	Trifolium hirtum	5	
	Filaree	Erodium spp	5	
	Medusahead	Taeniatherum asperum	5	
Auburn gravelly loam	Blue oak	Quercus douglasii		40
	Interior live oak	Quercus wislizenii		5
	Digger pine	Pinus sabiniana		5
	Poison-oak	Taxicodendron diversilobum		5
	Soft chess	Bromus mollis	40	
	Filaree	Erodium spp	5	
	Rose clover	Trifolium hirtum	5	
	Foxtail fescue	Vulpia myuros	5	
	Ripgut brome	Bromus diandrus	5	
	Wild oat	Avena fatua	5	
Orose	Interior live oak	Quercus wislizenii		25
	Blue oak	Quercus douglasii		5
	Digger pine	Pinus sabiniana		5
	Whiteleaf manzanita	Arctostaphylos viscida		5
	California black oak	Quercus kelloggii		5
	Toyon	Photinia arbutifolia		5
	Poison-oak	Taxicodendron diversilobum		5
	Ripgut brome	Bromus diandrus	5	
	Blue wildrye	Elymus glaucus	5	
	Squirreltail	Sitanion hystrix	5	
	Soft chess	Bromus mollis	5	
Stohlman	Blue oak	Quercus douglasii		10
	Soft chess	Bromus mollis	25	
	Wild oat	Avena fatua	15	
	Ripgut brome	Bromus diandrus	5	
	Filree	Erodium spp	5	
	Clover	Trifolium spp	5	
	Purple needlegrass	Stipa pulchra	5	
Palls	Blue oak	Quercus douglasii		40
	Soft chess	Bromus mollis	25	
	Wild oat	Avena fatua	15	
	Mediterranean barley	Hordeum leporinum	15	
	Common geranium	Geranium dissectum	10	
	Filaree	Erodium spp	5	
	California melicgrass	Melica californica	5	
	Ripgut brome	Bromus diandrus	5	
	Clover	Trifolium spp	5	
Sobrante loam	Blue oak	Quercus douglasii		40
	Soft chess	Bromus mollis	30	
	Rose clover	Trifolium hartum	10	
	Mediterranean barley	Hordeum leporinum	5	
	Ripgut brome	Bromus diandrus	5	
	Foxtail fescue	Vulpia myuros	5	
	Filaree	Erodium spp	5	

Table 1--Natural Plant Communities--continued.

Soil Series Phase	Characteristic Vegetation: Common Name	Characteristic Vegetation: Scientific Name	Percent Composition[1] Dry Wt.	Percent Composition[1] Canopy
Sobrante gravelly loam	Blue oak	Quercus douglasii		40
	Interior live oak	Quercus wislizenii		10
	Digger pine	Pinus sabiniana		5
	California black oak	Quercus kelloggii		5
	California buckeye	Aesculus californica		5
	Poison-oak	Toxicodendron diversilobum		10
	Buckbrush	Ceanothus cuneatus		5
	Soft chess	Bromus mollis	25	
	Wild oat	Avena fatua	10	
	Ripgut brome	Bromus diandrus	10	
	Clover	Trifolium spp	5	
	Filaree	Erodium spp	5	
	Silver hairgrass	Aira caryophyllea	5	
	Dogtail	Cynosurus echinatus	5	
Flanly	Interior live oak	Quercus wislizenii		30
	Blue oak	Quercus douglasii		15
	Digger pine	Pinus sabiniana		5
	California black oak	Quercus kelloggii		5
	Canyon live oak	Quercus chrysolepis		5
	California buckthorn	Rhamnus californica		5
	Whiteleaf manzanita	Arctostaphylos viscida		10
	Buckbrush	Ceanothus cuneatus		5
	Poison-oak	Toxicodendron diversilobum		5
	Toyon	Photinia arbutifolia		5
	Dogtail	Cynosurus enchinatus	5	
	Blue wildrye	Elymus glaucus	5	
	Wild oat	Avena fatua	5	
	Ripgut brome	Bromus diandrus	5	
Argonaut loam	Blue oak	Quercus douglasii		50
	Soft chess	Bromus mollis	25	
	Dogtail	Cynosurus echinatus	25	
	Wild oat	Avena fatua	10	
	Ripgut brome	Bromus diandrus	10	
	Foxtail fescue	Vulpia myuros	5	
	Rose clover	Trifolium hirtum	5	
	Medusahead	Taeniatherum asperum	5	
	Silver hairgrass	Aira caryophyllea	5	
Argonaut gravelly loam	Blue oak	Quercus douglasii		50
	Interior live oak	Quercus wislizenii		5
	Digger pine	Pinus sabiniana		5
	Poison-oak	Toxicodendron diversilobum		5
	Soft chess	Bromus mollis	25	
	Wild oat	Avena fatua	10	
	Ripgut brome	Bromus diandrus	10	
	Dogtail	Cynosurus echinatus	10	
	Filaree	Erodium spp	5	
	Rose clover	Trifolium hirtum	5	
	Silver hairgrass	Aira caryophyllea	5	

Table 1--Natural Plant Communities--continued.

Soil Series Phase	Characteristic Vegetation		Percent Composition[1]	
	Common Name	Scientific Name	Dry Wt.	Canopy
Verjeles	Interior live oak	Quercus wislizenii		25
	Blue oak	Quercus douglasii		5
	Digger pine	Pinus sabiniana		5
	California black oak	Quercus kelloggii		5
	Whiteleaf manzanita	Arctostaphylos viscida		10
	Toyon	Photina arbutifolia		5
	Poison-oak	Toxicodendron diversilobum		5
	Ripgut brome	Bromus diandrus	5	
	Blue wildrye	Elymus glaucus	5	
	Squirreltail	Sitanion hystrix	5	
	Soft chess	Bromus mollis	5	

[1]Percentage composition for grasses and forbs by dry weight. Percentage composition for trees and shrubs by percent canopy.

Table 2--Classification of the Soils (Soil Survey Staff, 1975)

Yuba County

Soil Series[1]	Classification
Argonaut	Fine, mixed, thermic Mollic Haploxeralfs
Auburn	Loamy, oxidic, thermic Ruptic-lithic Xerochrepts
Flanly	Fine-loamy, mixed, thermic Ultic Haploxeralfs
Orose	Loamy, mixed, thermic shallow Ultic Haploxeralfs
Sobrante	Fine-loamy, mixed, thermic Mollic Haploxeralfs
Verjeles	Fine-loamy, mixed, thermic Ultic Haploxeralfs

Sutter County

Soil Series[1]	Classification
Palls	Coarse-loamy, mixed, thermic Mollic Haploxeralfs
Stohlman	Loamy, mixed, thermic Lithic Mollic Haploxeralfs

[1]Soil Series descriptions are available on request from the Soil Conservation Service, 2121-C 2nd Street, Davis, Calif. 95616.

Table 3--Soil Vegetation Relationships Yuba and Sutter Counties, California, 1936

SOIL					VEGETATION			
Depth Class	Series Phase	Mean A.W.C.[1] (inches)	Bedrock	M.A.P[2] (inches)	Cover Type	Av. Basal Area (Sq. Ft.)	D.B.H.[3] (inches)	Mean Volume cords/acre
Shallow (10 to 20 inches)	Auburn loam	2.75	amphibolite schist (hard)	18 to 22	blue oak	141	9	37
	Auburn gravelly loam	2.25	greenstone (hard)	22 to 26	blue oak-int. live oak	69	14	21
	Orose	1.5	granodiorite (soft)	26 to 35	blue oak-int. live oak	135	8	38
	Stohlman	1.5	andesitic lahar (hard)	17 to 19	blue oak	--	9	12
Moderately deep (20 to 40 inches)		3.0	andesitic lahar (hard)	17 to 19	blue oak	--	12	93
	Sobrante loam	5.0	greenstone (soft)	22 to 26	blue oak	160	10	43
	Sobrante gravelly loam	4.0	greenstone (soft)	26 to 35	blue oak-int. live oak	161	10	97
	Flanly	5.0	granodiorite (soft)	26 to 35	blue oak-int. live oak	258	8	85
Moderately deep with claypan	Argonaut loam	3.5	greenstone (soft)	22 to 26	blue oak	133	10	19
	Argonaut gravelly loam	2.75	greenstone (soft)	26 to 35	blue oak-int. live oak	141	10	47
	Verjeles	5.0	gabbro diorite (soft)	26 to 35	blue oak-int. live oak	165	6	83

[1]A.W.C. - Available water capacity. Amount of water in inches held between 1/3 bar and 15 bar suction. Average for whole soil.

[2]M.A.P. – Mean annual precipitation, range for series phase.

[3]D.B.H. – Average diameter at breast height (4.5 ft.).

Species composition data for each site were obtained by visual estimate and by clipping, sorting and weighing each grass and forb species to determine the percent composition on a dry weight basis (table 1). The procedure is defined in the SCS National Range Handbook (SCS 1976). Composition for trees and shrubs by percent canopy was determined by visual estimate. Estimates were periodically verified by using a spherical densiometer for trees.

DISCUSSION

The volume data in table 3 represent 28 samples on 11 soil types. Sufficient ground control or sample quantity was not taken to provide statistically reliable information, but several inferences can be drawn from table 3.

Soil Depth and Available Water Capacity

Shallow soil series with bedrock at 25 to 64 cm (10 to 25 inches) had consistently lower cordwood volumes than moderately deep (50 to 100 cm, 20 to 40 inches) soils without a claypan. Volumes on the shallow soils averaged 27 cords per acre, 34 percent of the 80 cords per acre average on the moderately deep soils without a claypan. Presumably this is the result of shallower rooting depth and lower available water capacity in the shallow soils. Part of the lower volume may be a result of prior harvesting of oaks or fire and a failure of the shallow soils to regenerate oaks because of low available water capacity. Resprouts of blue oaks were observed on moderately deep soils and in the more mesic sites such as north slopes in areas where precipitation exceeded 660 mm (26 inches). No advance reproduction of this species was noted. In short, the blue oak was not being successfully reproduced. The most striking example of the effect of soil depth on cordwood volumes is in the soils found in the Sutter Buttes. Cordwood volumes were 87 percent higher on the moderately deep Palls soils than on the shallow Stohlman soils.

Bedrock Type

Hard unweathered amphibolite schist under Auburn loam soils is extensively fractured and often tilted to a nearly verticle [sic] angle. Roots were observed penetrating the fractures. One study documented roots of blue oak extending to 13 m (42 feet) or more in fractured and jointed metamorphic rock (Lewis and Burgy 1964). Roots were observed in only a few small fractures in hard massive unweathered greenstone under Auburn gravelly loam soils. Cordwood volumes on Auburn soils over amphibolite schist were higher than volumes on Auburn soils over greenstone, even though precipitation was higher on the Auburn soils over greenstone (table 3).

Greenstone under Sobrante soils is weathered soft in the upper part, normally about 1 foot, and becomes increasingly hard and massive with depth. There are very few fractures below 1 foot. No roots were observed penetrating in hard bedrock under Sobrante soils. In soils formed over soft, deeply weathered granodiorite such as Flanly, roots were observed to several feet in fractures in the rock. No roots were observed penetrating the hard massive andesitic lahar under Stohlman or Palls soils in the Sutter Buttes.

There may be differences in soil fertility due to differences in lithologies and other factors, but these are probably unimportant relative to physical differences in the soils.

Claypan

Argonaut and Verjeles soils, though they are moderately deep to bedrock, had cordwood yields that were 38 percent less than the other moderately deep soils. Argonaut and Verjeles soils have a distinct clay layer (claypan) that normally starts at 38 to 76 cm (15 to 30 inches) below the surface. The claypan lessens the effective depth that many roots can penetrate. Few fine roots were seen penetrating the claypan, however some coarse roots were observed in the claypan. The clay layer has a much lower hydraulic conductivity than the rest of the soil. Water moves through it very slowly and may perch above it during heavy rains. This wetness may have a significant effect on root development and thus production. Blue oak are not found on poorly drained soils (Neal 1980). Also note the mean available water capacity is lower on Argonaut soils than Sobrante soils. Argonaut soils have a lower A.W.C. because of the lower amount of water available in the clay layer. Both Argonaut and Sobrante soils are moderately deep to soft greenstone. Oak volumes in similar precipitation ranges were significantly higher on Sobrante soils than on Argonaut soils.

Climate

Precipitation also had an effect on production. Not surprisingly, Sobrante and Argonaut soils in the blue oak cover type had lower production than Sobrante and Argonaut soils in the blue oak-interior live oak cover type. Very little interior live oak was found at lower elevations in the 560 to 660 mm (22 to 26 inch) precipitation zone. With increase in elevation and precipitation and corresponding decrease in evapotranspiration, interior live oak becomes the dominant species at the highest elevations on such soils as Flanly (table 2). At the higher elevations the higher precipitation and lower temperatures equate to more moisture for plant growth.

Vegetation is highly variable in the blue oak type (Vankat and Major 1978, Neal 1980). Past occurrences strongly influence present stand structure and diversity. Extensive areas of Yuba County were burned in the 1930's and before. We have no way of knowing how fire affected the sites because of the slow response of these types to past disturbances, but perhaps one can assume that all were disturbed at least to some extent. The data on cordwood production may not represent the true productive capacity of the soils. However, care was taken to select sites that showed a minimum of disturbance and that had a plant community that was as close as possible to our predetermined potential for the soil (table 2).

Very little data are available on correlating soil properties to oak growth. Many problems in management of oaks, seedling survival and re-sprouting may be explained by soil properties. Based on our observations of the study areas, the odds are slim that blue oak will regenerate on any of these soils. The relatively low available water capacity and intense competition for water by understory plants make regeneration nearly impossible. Livestock grazing, rodents, insects, wildlife and fire and their interaction must be considered when managing blue oak and interior live oak. Stand density and diversity are, in part, related to the type of soil. Rundel (1982) noted that soil depth and the related effects of depth on soil moisture availability are the critical factors in separating the chapparal and foothill woodland communities in Sequoia National Park.

CONCLUSIONS

Soil properties are related to oak production. Soil properties are related to plant species occurrence. Soil properties and their limitations to oak growth should be identified first before more detailed steps are taken to manage oaks or conduct research on them. Soil survey information is available in nearly every county in California to help identify soil properties, including those that strengthen or lessen the likelihood of successful blue oak growth and regeneration. If during research the soil properties are identified, and the soil is classified according to "Soil Taxonomy", the results can be transferred to other areas of like soils with similar site characteristics.

Acknowledgements: We wish to thank Warren E. Peden, Soil Conservation Service, U.S. Department of Agriculture, for assistance in gathering and correlating data on vegetative composition and production.

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Economic Forces Affecting California's Hardwood Resource[1]

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Abstract: California's hardwood resource is affected by a range of economic forces that influence the availability of related benefits in different ways. Demand for hardwood products such as firewood may influence removal of hardwoods not only directly but also indirectly through land management activities that are aimed at increased production of other land-based commodities. Residential and agricultural expansion into hardwood areas may result in changes to the hardwood resource that, although not always immediately apparent, may be more permanent in nature.

THE HARDWOOD RESOURCE

Strong and growing market pressures, primarily from the firewood market, have been assumed to be promoting hardwood removal, but there has been little data on the actual influence of these markets or on possible future trends. This paper is based on a study designed to identify and analyze the major economic forces affecting California's hardwood resource.

Concern over California's hardwood resource has focused primarily on the removal of trees and the inability of some species to regenerate adequately. But the hardwood resource includes the environmental and societal benefits hardwoods provide as well as the trees themselves. These benefits are diverse and are related to the particular types of vegetative structures that comprise the wildland hardwood resource. Some of these benefits are realized in the production of wood products such as firewood, lumber, and pulpwood. Others are nonconsumptive and include wildlife habitat, visual quality, shade, and water protection. Effective hardwood resource policy must address the biological, social and political relationships associated with this broad range of hardwood-related benefits.

Several economic forces affect the distribution, availability, and flow of hardwood-related benefits. Like the benefits themselves, these forces are connected, often in complex patterns. They act both in concert and individually, and result in changes to the resource. For purposes of discussion, three types can be identified: 1) those operating directly through the demand for hardwood products; 2) those operating directly through land management decisions and indirectly through hardwood product demand; and 3) those operating directly through land use decisions with little or no connection to hardwood product demand. The first category includes the markets for hardwood firewood, pulp chips, lumber, and biomass. The second group includes management activities such as range and timber stand improvement. The last includes agricultural conversion and residential (and commercial and industrial) expansion.

HARDWOOD PRODUCT DEMAND

Hardwood products such as lumber, firewood and pulpwood are consumptive benefits of the hardwood resource. Because demand for hardwood products is manifested in tree removals, it is the most obvious force affecting the hardwood resource.

Firewood

Hardwoods are cut for firewood wherever they grow in the state. The oaks (*Quercus* spp.) generally command the highest price in the retail market, but several other native species are also burned, including madrone (*Arbutus menziesii*), tanoak (*Lithocarpus densiflorus*), bay (*Myrica californica*), and alder (*Alnus rubra*). Residential consumption of firewood, fueled largely by two major energy crises, increased dramatically in the 1970's.[3] As prices rose, new firewood cutters entered the market, previously unmarketable trees gained stumpage value, and hardwood removals increased. Such trends have led to a growing concern that demand for firewood is driving the widespread removal of indigenous hardwoods across the state, resulting in the loss of other benefits associated with their retention.

[1]Presented at the Symposium on Multiple-Use Management of California's Hardwood Resources, November 12-14, 1986, San Luis Obispo, California.

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[3]Regression analysis indicated a close correlation between gasoline prices and seasonal oak firewood prices in the *San Francisco Chronicle* from 1972 through 1985.

Although demand for firewood is an important force, its effect on the indigenous hardwood resource is mitigated by several factors. Native California hardwoods constitute only a small portion of the total firewood market. Although a relatively greater proportion of hardwood firewood than softwood is sold through retail markets, the majority of firewood consumed in the state is softwood. Much of this is cut for personal use from National Forests or private forestland. Growth in retail demand has prompted the development of other supplies of firewood including exotics such as eucalyptus, orchard wood (especially almond, walnut and citrus), and imports (both hardwood and softwood) from Arizona, Oregon, and even British Columbia.[4] This increased diversity of supply sources tends to buffer any effect that changes in firewood demand may have on indigenous hardwoods. Market indicators such as prices and numbers of firewood dealers in newspaper ads, and volumes of truck and rail imports from out of state, indicate that demand for hardwood firewood has stabilized considerably.[5] Additionally, the predominance of oak in retail firewood markets appears to have waned as softwoods and other hardwoods have gained greater consumer acceptance.[6] If demand for firewood remains stable, then the pressures on indigenous hardwoods for firewood are likely to stabilize as well.

[4]Southern Pacific records indicate an increase in firewood imports from the Northwest from approximately 148 cords in 1982 to over 6,000 cords in 1983. Pest Exclusion Unit records indicate over 7,500 cords imported by truck in 1983 via Interstate-5.

[5]Pest Exclusion Unit records showed decreasing volumes of truck shipments of firewood from the Northwest from 1982 through 1985. Rail shipments were found to be more erratic, but indicated an overall decline in volume from 1983 through 1985. Combined truck and rail volumes decreased only slightly from 1982 to 1985, with a high of 23,000 in 1983.

Analysis of newspaper firewood advertisements revealed that both the price of oak firewood and the number of advertisements decreased between 1980 and 1984. Based on a weighted sample of seven major newspapers, the real (inflation-adjusted) price of oak in December decreased by 92 percent from 1980 to 1984 while the number of firewood advertisements decreased by 78 percent.

[6]In 1980, 48 percent of all newspaper firewood advertisements analyzed were for oak while 20 percent were for orchard wood. In 1984 the share of oak advertisements decreased to 37 percent while orchard wood increased to 42 percent.

The proportionate share of hardwood shipped by truck via Interstate 5 decreased from 37 percent in 1982 to 7 percent in 1985.

Lumber

The hardwood lumber industry holds a small but constant share of total native hardwood consumption. The industry in California is currently limited to a single full-time hardwood mill.[7] The major hardwoods used for lumber are black oak, tanoak, and madrone. These are all found primarily on commercial timberlands. Any change in consumption in this sector, however, will have an indirect effect on rangeland hardwoods through horizontal linkages with the firewood market. Increased demand for black oak, tanoak and madrone sawlogs will tend to reduce their availability for firewood, shifting pressure towards other sources of supply, including the hardwood-rangelands.

Pulpchips

There are currently four operational wood-pulp mills in California. Although these mills rely on softwood chips, a small percentage of hardwood is often used in their total chip mix. Tanoak is used by two of these mills, both of which are on the North Coast where supplies are abundant.[8] The other two mills use eucalyptus and alder.[9] In late 1979, as a result of a shortage of softwood mill residue, overseas demand for tanoak chips rose considerably, and prices nearly doubled. Large quantities were shipped to Japan. Since the 1979 chip crisis, Japan has developed more reliable sources of fiber, and tanoak has not been exported from California for several years. Any increased consumption in the pulp and paper sector will, like the hardwood lumber sector, have an indirect effect on other hardwoods through horizontal linkages with the firewood market.

Energy production

There are currently 72 biomass projects in California using forest or mill residues to generate power. Sixty-six of these are co-generation plants, the remaining 6 producing only electricity. Six other facilities are under construction and nine more are in the planning stages (California Energy Commission, 1985).

[7]Cal Oak Lumber Company in Oroville, produces approximately 5,000,000 board feet annually.

[8]Tanoak cannot be utilized in production of higher-grade papers. Interviews with chip buyers indicate that approximately 60,000 cords of tanoak are consumed annually by the domestic pulp and paper industry.

[9]Eucalyptus and alder provide fiber highly desirable for the production of linerboard.

While the vast majority of these plants rely on softwood mill residues, some in-woods whole-tree chipping operations supply limited amounts of fuel. These in-woods operations occur on National Forest and private lands as precommercial thinnings, stand type conversions, or increased utilization during harvest operations. Thinnings and coversions [sic] are generally completed at a negative return to stumpage. Current chip prices barely cover chipping and transportation costs, and far exceed the costs of other fuels such as sawmill residue.

Although harvesting methods may become more economical, it is doubtful that delivered prices at biomass plants will translate into hardwood stumpage prices higher than those currently paid by firewood cutters. In some areas, demand for biomass will be in direct competition for orchard wood. This may reduce the supply of orchard firewood on the market, and subsequently increase demand for native hardwood firewood stumpage.

LAND MANAGEMENT

The removal of hardwoods is not always driven entirely by their value in commodity products such as firewood or sawlogs. Removals are often desired as part of land management objectives directed at other resource outputs such as softwood lumber or grazing for livestock. Range managers may want to improve the forage production of hardwood-rangeland by removing some or all of the hardwoods. Forest managers often remove individual hardwoods to release more valuable conifers, or convert entire hardwood stands to conifer plantations. Stumpage values can, however, play an important role in land management decisions by facilitating desired removals.

Range improvement

Range improvement through hardwood removal is an intensification of an existing use. It was historically undertaken to increase forage and livestock production. In this context the removal of hardwoods for range improvement is dependant on the profitability of the livestock industry and the net costs of removal to the landowner. Any increase in the profitability of the livestock industry or lowering of removal costs would likely result in increased hardwood removal. (Conversely, a decline in profitability or a rise in removal costs would likely lead to a decrease in hardwood removal.)

Firewood values have become increasingly relevant to hardwood-rangeland managers. The costs of past removals were often prohibitively expensive for an individual landowner, promting [sic] government assistance. Rising demand for firewood has lowered the costs of removal and aided in the accomplishment of desired range improvement objectives. As stumpage values rise beyond the costs of removal and clean-up, the incentive to remove hardwoods extends beyond any returns realized through range improvement alone. Much greater weight is placed on the stumpage value of hardwoods relative to both increased livestock production and hardwood retention value (for the production of such benefits as soil stability, wildlife habitat, aesthetics, etc.). If firewood stumpage prices rise, incentives to remove hardwoods will grow as the opportunity costs of their retention increase.

Declines in the profitability of the livestock industry place increased financial pressures on hardwood-rangeland owners. In these situations removal is more likely a short term "survival" response rather than an investment in range improvement. immediate cash flow problems may be most easily solved through capital liquidation in the form of hardwood stumpage sales. Although operating costs may be reduced due to resulting range improvements, the positive stumpage values and the need to survive play an important role in the decision.

Timber stand improvement

Intensive silvicultural practices that promote the removal of hardwoods from commercial timberland are also an intensification of an existing use. The main goal is increased production of softwood sawtimber. As with range improvement, the demand for hardwood firewood, lumber, and pulp chips can act as catalysts for these silvicultural activities. In some cases the revenue from these other markets may even become the primary objective. But hardwood stumpage values in commercial timberland are still relatively insignificant compared to softwood sawtimber values, and the return to hardwood stumpage generally has a minor effect on management direction decisions. The greatest removal pressures on hardwoods in commercial timberlands lie in those areas from which the combined costs of harvest and transportation to demand centers is lowest.

LAND USE CHANGES

While land management decisions such as range and timber stand imrovement [sic] may be influenced by hardwood stumpage values, other land use decisions affecting hardwoods are not. Conversion of hardwood-woodland to intensive agricultural use or to residential, commercial and industrial development are changes in land management direction. Decisions leading to use changes are related only to the expected value of the proposed use relative to maintaining the current management direction. Although hardwood stumpage may be sold in resulting clearance operations, the value of that stumpage is not a factor in the decision process.

Agricultural conversion

Agriculture is one of the largest sectors of California's economy. Expansion of this sector often occurs in the hardwood-rangelands bordering existing agricultural lands. Soil, topography, climate, and technology limit the potential for development.

Conversion of hardwood-rangelands to intensive agricultural production continues in certain areas of California. San Diego County has the largest number of acres being converted to intensive agriculture. The rapid expansion of avocado orchards is removing many acres of wildlands within the potential range of Engelmann oak. Agricultural counties such as Monterey and Tehama are predicting large increases in intensive agricultural acreage. Much of this expansion will occur in hardwood-rangeland.

The introduction of drip irrigation technology has reduced production costs enough to allow increased agricultural development of many grazing areas. In Tulare County it played a significant role in allowing expansion of citrus orchards into the hardwood-rangelands on the perimeter of the San Joaquin Valley. Drip irrigation, along with high grape prices, increased the introduction of small vineyards in the hardwood-rangelands of Monterey, Sonoma, Napa, and Mendocino Counties. Fruit orchards have recently been introduced into the hardwood-rangelands in the Sierras and in Mendocino County.

Parcelization and residential expansion

Like agricultural conversion, residential expansion into hardwood areas is a permanent change in use that, although it may provide firewood, is not influenced by firewood or other wood product demand. Residential expansion may entail some loss of hardwood cover, but parcelization and residential expansion also result in a permanent change in management direction, with new owners and managers using the land quite differently from managers of larger commodity producing land units.

Residential development is affected by economic and social forces with very little connection to the commodity markets for wood products or livestock. The land supporting hardwoods is valued for its location and production of amenity values. The dynamics manifest themselves in the land market. Because of rapidly increasing population and changing lifestyles, greater numbers of people desire to live in rural areas. The hardwood- rangelands provide an ideal environment for this new population. These lands are largely privately owned and relatively less expensive to develop than areas closer to urban centers. They are also closer to urban work centers than commercial timberlands, while still providing the amenities of living in a rural area. It is unclear what the real effects of parcelization and changing land use patterns are on the hardwood resource, although the allocation of benefits associated with hardwoods will change over time.

Residential expansion into hardwood-woodlands is most noticable [sic] in many of the Sierra foothill counties such as Nevada, Placer, El Dorado, Amador, and Calaveras. Other counties with high growth in hardwood areas include Monterey, Sonoma, Lake and San Diego. Practically every county in the state with any expanse of hardwood-woodland is experiencing some degree of change brought on by residential growth in those areas.[10]

CONCLUSION

There are a wide range of economic forces having an equally wide range of effects on California's hardwood resource. These effects are manifested not only in the removal of hardwoods, but in changes in land use and management direction that have differing degrees of permanence [sic].

The mere existence of hardwoods does not dictate the structure and magnitude of the biological and societal benefits associated with them. The production and availability of hardwood-related benefits can be significantly affected by forces that may have little or no effect on the existence of individual trees. Demand for hardwood products such as firewood can act to remove a multitude of benefits while in effect cashing in on one. But other forces, such as the demand for residential parcels, can greatly alter the availability of hardwood-related benefits even while ensuring the retention of the trees themselves. The process of changing ownership, parcel size, and residential occupation may result in a reduction in the number and extent of oaks and other hardwoods through land clearance and firewood production. But more importantly, the character of the land is altered by multiple new owners and their often inconsistent activites [sic]. Land is removed from large scale commodity production, state fire protection costs increase,

[10]The Central Sierran counties of Nevada, Placer, El Dorado, Amador, Calaveras, Madera, Tuolumne and Mariposa, with an average annual growth greater than or equal to five percent, were all in the top twelve high growth counties in the state between 1970 and 1985. All of these counties are characterized by extensive privately owned hardwood woodlands. During this same fifteen year period a total of 172,617 acres in these eight counties were subdivided into 59,587 lots, an average of 2.9 acres per lot (California Department of Real Estate). These figures include only formal subdivisions. Informal subdivisions of four lots or less are more difficult to track although they may cover more territory.

wildlife requirements and management become more complicated, and future patterns of water requirements are affected. Unlike firewood production which may temporarily remove hardwoods (and their associated benefits) from the land, land use changes such as residential expansion are essentially permanent.

Acknowlegements [sic]: This study was funded by the Forest and Rangeland Resource Assessment Program, California Department of Forestry.

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Recognizing Hardwood Quality: Key to Increased Profits?[1]

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Abstract: In order to maximize the dollar return from California's hardwood resources, that industry must allocate the resource to its best end use and strive to increase the utilization of all material presently considered waste. To achieve the proper allocation of this resource to its best end use, you must be able to recognize and accurately classify the quality characteristics of standing timber, cut logs, and end products. Quality classification and grading systems allow us to segregate the tree or its parts into groups, all with similar characteristics. This enables the individual to determine value and predict the volume of end products. Although most hardwood systems have been developed for eastern hardwoods, they have also been applied to western hardwood species. These systems are essential for timber appraisal, timber inventory, and quality control during processing. The accurate prediction of end product yield and value allows the individual or company to be more confident of their management and marketing decisions.

When we think in terms of timber quality, we usually consider one of two aspects: channeling the log, tree, or stand to its best end use or uses; or maximizing the total dollar value. These two may or may not be the same. But as our national supply of high-quality hardwood timber decreases, we must make better use of the resource; that is, we must allocate our timber supply more efficiently and find additional uses for those parts of the log or tree that traditionally were discarded as waste. To accomplish this we need classification and grading systems that can accurately measure the quality characteristics of trees and logs. Such systems aid in minimizing the biological variation inherent in a group of logs or trees by segregating the tree or its parts for specific uses and into various classes based on each use. Therefore, as Brisbin (1985) states, an accurate evaluation of quality is especially important in potentially high-value hardwoods where the differential in price between high-quality and low-quality end products is large.

The West Coast hardwood industry must either adopt the East Coast lumber and log grading rules, or modify them to fit their needs or requirements. For only through the use of such grading systems will you be able to define and measure the resource as well as design the proper mills to utilize it. Studies by the University of California's Forest Products Laboratory have shown that the USDA Forest Service hardwood log grade specifications (Rast et al. 1973) were suitable for use in segregating tanoak (Dickinson and Prestemon 1965), golden chinkapin (Prestemon et al. 1965), and Pacific madrone (Dickinson et al. 1965) logs into quality classes showing distinct differences on grade yield of hardwood factory lumber. Only California white oak (Dost et al. 1966) required modification of the USDA Forest Service standard grades for hardwoods. Probably additional studies in all species are needed since the number of logs in the individual studies ranged only from 53 to 93. Studies in the East normally had a minimum of 300 to 500 logs in each species sawn at several different mills.

For years, the attitude was that hardwoods were a weed species or a nuisance that just increased the cost of logging or reestablishing softwoods. This attitude must be changed as well as the attempt to try to harvest and saw hardwoods like softwoods; that is, 16-foot logs or to the closest 2 foot.

There have been conflicting reports on the quality and availability of hardwoods, particularly in the East, but the same is probably true for hardwoods on the West Coast. While some lament the decline in quality, others insist that the general quality is improving. Market conditions, coupled with availability, have a great influence on people's opinions. But as buyers and sellers of timber, there is one

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thing we can all agree on--that hardwood timber varies greatly in quality and value, not only within species, but also within geographic areas and individual stands.

USERS OF GRADING SYSTEMS

There are four groups who can benefit from an understanding of timber quality and a knowledge of grading systems (Brisbin 1985). These include timber managers, timber appraisers, loggers, and primary processors of forest products. Grading systems enable land managers and foresters to estimate the present and future value of individual trees in a stand. This allows them to make sound silvicultural and economic decisions on which trees to mark for cutting and which to leave. Also, timber management practices cannot be evaluated adequately without a means of measuring their effect on both the quality of the residual stand and the quantity of wood produced. And timber appraisers can use classification and grading systems to estimate the value of a tract of timber for purchase or sale.

Loggers obviously play an essential role in producing high-quality products from trees. The decisions that a feller makes during the felling, and especially bucking of a tree, can greatly affect the dollar return of the resulting end products. The following are some of the variables that the feller should consider in addition to bucking for grade (USDA Forest Service 1975):

1. Proper stump height. Unless rot is present, some of the highest quality wood is in the area of the stump. Not cutting at the proper height for a particular tree can cause a considerable loss in log volume and affect the grade of the log by lowering the diameter at the small end of the log.

2. Proper log length. Cutting a log shorter than the standard length or without proper trim usually means that the mill scaler will scale it as a shorter length log or reject the log. Excess trim also means a loss of volume in the other logs bucked from that tree. Log grade must be considered when discussing length since an 8-foot log cannot be grade 1 by USDA Forest Service grade standards.

3. Proper end cuts. Diagonal cuts on the end of logs lead to a reduction in the log length at the mill or an unnecessary loss of log length on subsequent logs in the tree.

4. Proper bucking for crook and sweep. By cutting to minimize crook and sweep, scale and grade can be improved. The best bucking position usually is at the point of maximum crook and sweep. Although a jump-cut (cutting out an unmerchantable section) will reduce total tree volume, sometimes this can be more than compensated for by an improvement in the grade of the log.

5. Proper placement of defects. After diameter, defects are the primary factor in determining log grade. The person bucking the log must consider defect placement during bucking, that is, try to place defects near the end of short logs and near the center or end of long logs.

Primary processors need grading systems not only to purchase raw material, but also to allocate logs to their best end use. Grading systems also are useful for estimating expected volumes of the different end products that a processor may produce from a given group of logs.

Finally, the use of grading systems helps owners and managers of private, nonindustrial woodlands determine the volume and value of their timber holdings. Such evaluations could result in a more productive use of these woodlands where timber production is compatible with owner objectives.

EVALUATING QUALITY

Englerth (1966), in his evaluation of qualitative relationships in wood utilization, states that only after end products to be produced are defined can timber quality be estimated, since product end use and performance requirements must be related to tree and wood characteristics. Most quality classification and grading systems in use today were developed using tree and wood characteristics that significantly increase their ability to predict actual volume and value of the desired end products.

As Brisbin (1985) states, relatively few tree and wood characteristics of a given species affect the end-use requirements of most products. The most important ones are:

1. Growth rate and bole form of the tree
2. Specific gravity
3. Knots and limb-related defects
4. Decay and insect damage
5. Size of tree

Slow and uniform growth of a tree is probably the most desired from the manufacturer's standpoint for processing and drying. Particularly in veneer, erratic growth causes problems in slicing and, more importantly, in drying. Abnormal growth also affects the grain pattern in both veneer and high-quality factory lumber. Abnormally fast growth affects the uniformity of chips, causing potential problems in such products as orientated-strand board and structural particle board. Crook or sweep in a tree affects its suitability for most solid wood products. It also affects volume recovery and increases harvesting and production costs. The strength of structural products as well as the yield of pulp fiber are adversely affected by low specific gravity. Growth rate, tree age, and specific gravity are all interrelated. Almost all solid or reconstituted products are adversely affected by knots, limbs, decay, and insect damage. Tree size, mainly diameter, is probably the most important quality indicator for most solid wood products.

Because wood is a biological material and no two trees are exactly alike, it is difficult to predict the exact effect that specific tree and wood characteristics will have on the end products. The primary purpose of quality classification and grading systems is to reduce this biological variation by segregating the tree or its parts for specific uses. The grades are a measure of quality. As such, they become the basis for nearly all processing decisions. Economics and market demand may determine the value of a particular grade for a given set of circumstances, but the wood characteristics alone should determine the actual grade (Brisbin 1985).

Specifically, quality classification and grading systems are useful for (1) classifying young growing-stock hardwood stands to relate present quality characteristics to future product potential, and (2) predicting the quality of trees and logs that have potential to be converted immediately into primary products.

HARDWOOD LOG AND TREE GRADES

Many grading systems have been developed and used over the years to facilitate the buying and selling of logs and trees. To be effective, a grading system must be developed from a carefully selected data base, provide consistent results, be easily understood and applied by a wide range of individuals, and predict accurate yields of end products. The Forest Service Standard Hardwood Log Grades meet all of these requirements. Approximately 20,000 logs sawed at more than 75 sawmills throughout the Eastern United States made up the data base for this grading system. The grading specifications are closely correlated with those for standard factory lumber grades (Cassens and Fischer 1978) published by the National Hardwood Lumber Association (NHLA 1982). The yields are expressed as a percentage of NHLA grade yields (Hanks et al. 1980). The grading factors to be considered in applying Forest Service Log Grades are (Rast et al. 1973):

1. Position of log in tree (butt or upper)
2. Log diameter
3. Log length
4. Number and location of grade-reducing defects
5. Amount of crook and sweep
6. Amount of cull (rot, holes, etc.)

Although the grading specifications seem complicated to the inexperienced log grader, we have found that most people learn the grades with a little practice. Also, there are several publications that can help the grader recognize defects (Marden and Stayton 1970; Shigo 1983; Rast 1982; Rast and Beaton 1985). Two of the more important conditions for learning to grade are practice grading and observing graded logs being sawed. Hanks et al. (1980) provided lumber grade yield tables by log grade and scaling diameter for 16 species and two groups of lowland oak species. By applying current lumber prices to the predicted yields, you can estimate the value of the lumber that can be sawed from the graded logs. Therefore, by deducting appropriate costs (logging, hauling, milling, etc.), you can estimate the value of a group of logs. Yaussy and Brisbin (1983) developed multivariate regression equations to predict expected board volume by lumber grade. This form is more compatible with computer applications.

Log grade systems are useful for determining board-foot yields, lumber grade recovery, and subsequent log value, but are awkward for estimating the quality of standing timber. Tree grades for predicting factory lumber yields were developed by Hanks (1976); yield equations were developed for northern red, black, white, and chestnut oak; red and sugar maple; yellow and paper birch; basswood; black cherry; yellow-poplar; and aspen. Tree grades, like log grades, group trees by high, medium, and low quality based on predicted lumber grade yields. Many of the same factors used in log grades also apply to tree grades--size, surface characteristics, straightness, and soundness. Since many of the steps used to grade a tree are used to determine volume, the added cost of tree grading during cruising is minimal.

Little work has been done on using log grading systems to predict veneer products. Each manufacturer's requirements usually depend on the customer's specification. Most company and independent log buyers have specifications that are tailored to meet a particular end product. As a result, it will be difficult to develop a standardized veneer grading system. Veneer log specifications have been published (Northern Hardwood and Pine Manufacturers Association 1976; Rast 1975), but do not include expected product yields for veneer. However, these grading systems can still be used by foresters, timber buyers, and timber sellers to estimate the volume of veneer in logs that meet general veneer specifications.

Because of changing market conditions and the species composition of many stands, emphasis is being placed on production and market acceptance of structural lumber from hardwoods. Denig et al. (1985) have completed preliminary work on log grades for estimating yields of structural dimension lumber from yellow-poplar sawlogs. Their modification of the existing softwood log grades provides statistically sound predictions of hardwood structural lumber. Since hardwood log grades for factory lumber are based on the amount of clear wood in the board, these grades are unacceptable for grading structural lumber because structural lumber utility is based on strength-reducing characteristics. For example, a board with a single large knot (whose diameter is less than one-third of the surface measure) may still qualify as an FAS board in factory lumber, but it may be unsuitable as a structural board. Grade and span tables are available for yellow-poplar framing lumber (Allison et al. 1985).

Although most hardwood log grading systems are based on the yields of one end product, namely factory grade lumber, most hardwood trees are suitable for conversion into two or more products. As an example, a white oak tree may be processed to produce fancy face veneer, stave bolts, high-grade lumber, special structural timbers, railroad ties, posts, or pallet lumber.

It is now possible to appraise hardwood timber for these multiple products by applying separate log grade product specifications individually to the sample tree. But research is in progress to develop multiproduct grading systems for sawtimber-size trees. Blinn et al. (1983) described a method for estimating the multiproduct value of hardwood timber stands that is based on making product suitability decisions about each sample tree in that stand. The measurements and estimates are then aggregated for the stand to calculate volume and value per acre for each potential product.

Yaussy and Sonderman (1984) developed a preliminary model for partitioning the total tree cubic volume into a maximum of four round product groups. The only measurements required to predict volume by product group are d.b.h., total height, number of limb-related defects in the butt 16-foot section, and an estimate of epicormic branch severity. The four product groups for which volume predictions are made are veneer logs, Forest Service grades 1 and 2 sawlogs, Forest Service grade 3 and construction grade logs, and fuel and fiber. The model demonstrates the feasibility of predicting product yields from several easily measured tree characteristics.

Information is available for all of the previously mentioned grading systems, and slide-tape programs are available that explain and demonstrate the use of both the hardwood log and tree grades, but one of the most effective methods of learning to apply hardwood log or tree grades is attending a grading workshop. In the East, these courses are offered by universities and through state forest organizations; hopefully as hardwoods become a more utilized resource on the West Coast, this will become a standard practice in your area.

QUALITY CLASSIFICATION FOR FUTURE PRODUCT POTENTIAL

Young hardwood growing-stock stands represent a large portion of the hardwood stands in the East. If we are to practice good timber management and economics, we need a system for predicting the future product potential of these young stands in which we plan to apply cultural treatments. Although considerable research has been conducted on the effect of timber management practices on tree growth rates, there has been only a limited amount of work on timber quality development. In dealing with medium- and high-value hardwoods, quality change over time is as important, if not more important, as growth rate.

No industry can be static and remain viable over a long period of time, and the forest products industry is no exception. As this industry changes, we can expect to see end-product specifications change as well as a competition develop for the limited forest resource used for end products. Therefore, a tree-quality classification system for young hardwood growing-stock trees must not be tied to specific current product specifications, but be more biologically descriptive of the tree.

Assuming that we have selected the appropriate tree characteristics, described them by an array of numerical values, and aggregated them for a given stand, it should be possible to interpret these at any point in terms of current or newly developed product standards.

Sonderman and Brisbin (1978) and Sonderman (1979) investigated different potential quality-related tree characteristics and examined their occurrence and variation in natural and culturally treated young stands. Dale and Sonderman (1984) and Sonderman (1984a,b) described the response of several tree quality characteristics in young hardwood stands to various levels of thinning treatments. This research showed that thinning treatments significantly affect the number and size of limb-related defects in the more valuable butt portion of hardwood trees. Thinning below the

B level (60 percent stocking) usually is detrimental because it stimulates epicormic sprouting and retards natural pruning.

Individual-tree growth and quality responses to intermediate thinnings are being integrated into comprehensive computer programs for many forest types. These programs allow users to study the effects of the type, timing, intensity, and frequency of thinnings on growth and quality development. For example, Dale and Hilt (1986) used OAKSIM (Hilt 1985a,b), an individual-tree growth and yield simulator for even-aged upland oak stands, to test various thinning strategies for oak stands growing on medium and good sites (black oak site indices 60 and 80, respectively). Results indicate that 80-year rotations are not feasible on medium sites because only a few trees are large enough (16 inches) to qualify as grade 1 trees, even if thinning is applied. Longer rotations are required. Thinning on good sites, however, can produce 20 to 30 grade 1 trees per acre at age 80.

These kinds of computer simulation studies can be run for a wide range of age, site, stand, and thinning conditions. This information, coupled with economic analyses, is extremely valuable for making long-term decisions on how to grow high-quality timber.

SUMMARY

We believe that most landowners are interested in increasing profits from their investment in forest lands. It may not be the prime reason for owning forest lands, but it is almost always compatible with other objectives if the proper management plan is selected and care is taken in selecting a logger. To achieve your goals, you must first be able to recognize and utilize the timber quality available by applying a grading and quality classification system. These can be used in appraisal, inventory, quality control, and mill design.

Obviously there are many factors to be considered in management strategies by landowners or managers, such as current and future prices, markets, landowner objectives, and transportation. However, if the combination of product yields that are physically possible from a stand of timber or group of logs can be predicted accurately, then all of the management and marketing alternatives can be evaluated adequately and informed decisions made.

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Cal Oak-Staying Afloat in the California Hardwood Lumber Business[1]

Richard Wade and Guy Hall[2]

Abstract: Cal Oak Lumber Company of Oroville, Calif., has operated for 21 years as the state's largest manufacturer of goods made from native California hardwoods. The Company's history and current operations are described to illustrate two decades of evolution in the utilization of California hardwoods. Problems and opportunities in producing and marketing lumber, firewood, and pulp chips from seven hardwoods indigenous to northern California are outlined. Changing market conditions for these products has caused Cal Oak to revise production goals and strategies, to improve manufacturing techniques, and to attempt to expand the uses of and markets for native hardwood products.

The prospect for success in manufacturing lumber and other products from California's native hardwoods does not rest entirely upon such technical aspects as having an adequate raw material supply, or the suitability of the wood for making lumber. Assuming that these conditions are given, the manufacturer must also be able to produce quality goods with economic efficiency, to compete with more established species in hardwood markets, and to be responsive to changing and emerging markets.

Cal Oak Lumber Company of Oroville, Calif., has taken the step from simply recognizing the potential uses of California hardwoods to actually utilizing the resource in the manufacture of an array of products. Having met for 21 years the above criteria for survival, Cal Oak stands as an example of durability and longevity in a business most noted for its failures.

The experience of Cal Oak will serve here to illustrate many practical aspects of large scale, diversified utilization of the native hardwood resource. In this discussion, I will first briefly relate Cal Oak's history as it reflects an evolution in the utilization of the native hardwood resource. The current market conditions for California hardwood products will be described from Cal Oak's perspective. I will then outline Cal Oak's recent efforts to remain competitive in these markets through changes in production strategy and end product outputs, and through innovation in the use of native woods.

In conclusion, general characteristics of the California native hardwood business and some elements necessary for a firm's successful venture into this arena will be identified.

HISTORY

Cal Oak Lumber Co. was begun in 1965 by forester Guy Hall, who entered into a joint venture with a local sawmill operator to move and redesign an existing sawmill to cut oak in Oroville, Calif.

At that time, there was little utilization of native hardwoods for any purpose. Considerable knowledge had been gained by researchers indicating the potential suitability of California hardwoods for lumber, but such conclusions had been largely untested outside the laboratory. Isolated, large scale processing of hardwoods had occurred over the years, with the use of tanoak (Lithocarpus densiflorus) for flooring and of other hardwoods for lumber, but there was no ongoing hardwood-based industry. In the Sierra, many forestland managers, primarily public, saw the loss of conifer growth due to hardwood competition, and actively pursued the trees' destruction by poisoning and girdling.

Early Utilization by Cal Oak

Most of the lumber sawn during Cal Oak's early years was sold as pallet shook. Then, as now, the primary species was California black oak (Quercus kelloggii), although irregular cutting of tanoak, madrone (Arbutus menziesii), valley oak (Quercus lobata), sycamore (Platanus racemosa), and other species occurred. Recovery of upper grade boards was not a primary goal, although some were sold as rough, green FAS grade. At this time, only the clear main bole of large, sound and straight trees was brought to the mill, and all limbs were left in the woods. Mill residues were disposed of by burning.

Emerging Markets

During the 1970's, market conditions and improvements in processing technique allowed diversification into products other than industrial grade lumber. These factors included a.) an increasing demand for firewood and for pulp quality wood chips for export; b.) a growing ability by Cal

[1]Presented at the Symposium on Multiple-Use Management of California's Hardwood Resources, November 12-14, 1986, California Polytechnic State University, San Luis Obispo, Calif.

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Oak to produce and sell kiln dried, surfaced lumber from many native species, including short, clear boards recovered from pallet cuttings; and c.) an end to the burning of mill wastes, forcing Cal Oak to find other means of disposing of residues.

In light of these developments, Cal Oak made several major changes.

The Mini Mill--To increase lumber production and recovery to meet market demands, a second "mini" mill was designed and built. While the original mill, refitted with a bandsaw headrig, continued cutting large logs up to 16 feet long, the "mini" mill sawed logs from crooked boles and limbs to make pallet shook and short clear boards. It also employed a bandsaw headrig to reduce the residue and greatly increased the utilization of an individual tree.

In 1972, a pallet line was built capable of producing some 1200 pallets per day. This was a first step to diversify into secondary manufacturing and achieved a modest vertical integration.

Slabs and ends from the mills were diverted from the now obsolete teepee burner, cut to length, dried, and sold as firewood. The first boxed firewood product was introduced by Cal Oak in 1976, utilizing this slabwood as a portion of its contents.

In 1974, the "big" mill was sold. The "mini-mill" had been modified to saw logs to 54" in diameter, and 40" to 8 feet long, so as to recover both upper grade and pallet lumber. A new chipper added to the "mini-mill" to process either its residues, or to chip whole logs independently of the mill's operation.

A detailed history of the Company and its makeup by the late 1970's is in Cal Oak's report to the 1979 Oak Symposium at Claremont (Hall and Allen 1980).

CAL OAK TODAY

Cal Oak in 1986 can best be described as an integrated hardwood processing facility. Facilities include the sawmill, which still uses the carriage system to cut short logs, Kockums chipper, lumber remanufacturing facilities such as a cutup/rip line, resaw, and new equipment to produce decorative boxes, wood splatters, and a firewood packaging line, plus warehouses for firewood and lumber storage.

In 1985, about 50,000 tons of logs were procured. Sawmill output included the production of 3.3 million board feet of lumber, of which 1.4 million was upper grade (#2 Common & Better), 5,000 tons of pulp quality wood chips, and 5,000 tons of sawdust and other residue. Approximately 10,000 cords of firewood were inventoried and/or processed, ranging in form from logs to a fumigated box of kindling.

In retrospect, there has been a constant evolution of the type and relative amount of goods produced at Cal Oak, a reflection of their ability to create and develop a niche for native species in hardwood lumber markets, while diversifying production to capitalize on opportunities in the markets for firewood and pulp chips. As markets grew and hardwood products became more diverse, it became increasingly important to allocate incoming logs and to adjust production to outputs which would maximize returns relative to production costs. While overriding factors such as limited investment capital, raw material availability, technical limitations or advancements, and litigation have influenced product output at Cal Oak, it is the relative market values of hardwood lumber, firewood, and pulp chips which have largely dictated the mixture of outputs.

CURRENT MARKETS

The following section describes, from Cal Oak's perspective, the current standing of native hardwood products in the markets for hardwood lumber, firewood, and pulp (or fuel) chips. For each end use, Cal Oak's recent attempts to remain competitive in the market will be identified.

The Hardwood Lumber Market

Furniture, flooring, millwork, pallets, timbers, and ties are a few of the many end uses of the approximately 83 major commercial hardwood species growing in the United States (U.S. Forest Products Laboratory 1974). In 1985, production of hardwood lumber in the United States was about 6 billion board feet, most of which was produced east of the Mississippi River. Industries which utilize high grade domestic hardwood lumber are largely oriented by history and tradition to the use of eastern lumber species, with a few exceptions, such as red alder (*Alnus rubra*). This is true even of hardwood lumber consumers in California, which in 1982 ranked second only to North Carolina in the U.S. furniture industry by value added by manufacture (Hoover 1986).

From Cal Oak's standpoint, the market for native hardwood lumber is divided into 2 broad categories; that which is used for furniture, flooring, moulding, and other high end uses, and that for industrial uses such as pallets, dunnage, and timbers.

The Upper Grade Lumber Market

Within Cal Oak's procurement area, about a 120 mile radius from Oroville, grow 7 species from which upper grade lumber is recovered by the Company. These include California black oak, valley oak, California sycamore, black walnut (*Juglans hindsii*), Fremont cottonwood (*Populus fremontia* , tanoak, and madrone. All are kiln dried, surfaced, and graded according to National Hardwood Lumber Association grading rules or to specifications developed by Cal Oak for short lumber.

The major characteristics which dictate the marketability of each species is a.) its substitute-bility for lumber of eastern hardwood species in the marketplace, b.) the degree of difficulty in producing a quality board or adapting the wood to a given use, and c.) the availability of the raw material in consistent volume.

Impediments to Marketing of California Natives--Despite any inherent qualities of these woods, and Cal Oak's ability to routinely produce quality lumber, the sheer size and diversity of the eastern hardwood industry is a great advantage to eastern manufacturers. For example, many secondary manufacturers are reluctant to promote a product line utilizing a native species when there are so few producers of that lumber. The limited production of western hardwood lumber severely limits the variety of lumber dimensions available. The many eastern producers, each striving for a niche in the market, ensures that a broad range of thicknesses, widths, and lengths of eastern hardwood lumber is available.

Despite transportation costs to the West Coast, lumber prices of eastern species comparable to western natives are often extremely competitive here. Although Cal Oak's production capacity is similar to that of an eastern hardwood sawmill, middlemen in the east often consolidate the production of many mills to increase the efficiency of kiln drying, grading, marketing, and transporting lumber (Hoover 1985).

There is a lack of matching products for native California hardwoods, such as veneers and moulding stock. Although complementary products can be found, this deters many manufacturers who use such components from using California natives.

Many early attempts at making lumber from indigenous woods were poorly done, resulting in lumber which was not properly dried, and thus tended to warp or check while in service. Some residual prejudice is found for that reason.

Advantages of California Species--Notwithstanding these general impediments to marketing California natives, there are obvious advantages to the California producer, including low transportation costs to local markets, better customer service, and the ability to sell smaller quantities at wholesale. The unique appearance and lumber quality of each California species is the major selling point.

Status of Individual Species

The following is a brief description of the current status of the upper grade lumber of the 7 species milled at Cal Oak:

California Black Oak--This species produces a red oak lumber which is the mainstay of Cal Oak's operations, about 80 percent of the Company's annual upper grade production. Red oak lumber, produced from at least a dozen eastern oak species, is preeminent in American furniture and woodworking industries. Lumber from California black oak, while closely resembling Appalachian red oak in some logs and Northern red oak in others, has superior machining qualities and a tighter, distinctive grain pattern with more figure which make it desirable for many uses. Current major buyers of black oak lumber are woodworking and cabinet shops, building contractors, and hobbyists, using the lumber for furniture, cabinets, boxes, and other applications.

Raw material is available in good quantity and careful processing makes technical problems with the lumber very rare. As will be discussed further, Cal Oak is expanding the application of this lumber to flooring, paneling, and doors.

White Oak--An attractive, very durable white oak lumber is cut from the valley oak, which compares favorably with and is easily substituted for its eastern counterparts. However, the lumber is produced in small, irregular quantities due to limited raw material. Valley oak presents a variety of challenges in all phases of lumber manufacturing, including a propensity for fungal stain in the lumber, and a tendency to collapse while drying.

Because of its generally high quality and Cal Oak's success in controlling these problems, much more native white oak lumber could easily be sold than is produced.

Sycamore--Lumber of good quality is produced from this species, with few technical problems. California sycamore lumber is easily substituted for eastern sycamore and is in modest demand for drawer sides and for woodworking. As this is a riparian species and logs are seldom generated, the supply of the lumber is erratic. Since whatever is sawn at Cal Oak is usually quickly sold, there has been little effort to expand the uses and markets for sycamore.

Black Walnut--The market for material from this species, including gunstock blanks, and burls and veneer bolts for export, is very lively the State. Lumber from California species closely resembles eastern walnut, although the color is often more varied. Sources of logs, including orchard grafts, old plantings along roads and around homes, and riparian areas, all offer difficulty in obtaining raw material for lumber, so quantities produced at Cal Oak are modest. The grade recovery in lumber is often low due to poor logs from open grown trees.

Fremont Cottonwood--When sawn, this species produces lumber which, while not having the strength characteristics of dense hardwoods, is often laced with birdseye and other attractive grain patterns. Characteristics which impair its marketing for upper grade uses are several, prominent of which is the tendency for torn grain. The lumber has limited substitutability. The supply of raw material is limited to some degree due to its riparian nature.

Since Fremont cottonwood mill residues and low grade logs have little value for firewood, the successful sawing is especially dependent upon a strong market for the pallet shook invariably generated, even when sawing for upper grade. The absence of a strong demand for pallet lumber made this species impossible to cut profitably in 1986.

Tanoak and Madrone--These species, while differing in appearance and wood characteristics, are similar to one another in their current utility and marketing strengths. Although difficulties in lumber manufacture are inherent, due to tree form and wood characteristics, Cal Oak routinely produces quality upper grade lumber from them. Tanoak and madrone are not immediately substitutable for eastern species; however, favorable characteristics indicate that each can become a major commercial species. Madrone has an attractive and unique appearance, outstanding machining properties, and is durable. Tanoak is very stable when processed properly, has excellent strength, and an oaklike appearance.

The availability of raw material is not a serious limitation. The major current use of upper grade tanoak and madrone lumber cut by Cal Oak is for furniture, and their use for flooring is increasing.

The Low Grade Lumber Market

Equally importance to California hardwood lumber producers is the market for low grade lumber, consisting of shook for pallets, timbers, dunnage, and other industrial uses where strength, not appearance, is needed. By nature, California hardwoods yield a high percentage of low grade lumber due to poor tree form and the high incidence of knots and such defects as rot and shake. Irrespective of the production goals, this low grade lumber will always be a significant portion of output.

Over the past several years the market for pallets and shook has been unfavorable. In the late 70s, large grocery retailers came to accept pallets using red alder, previously felt too weak for exchange pallets. Although alder pallets are still considered inferior by industry standards, demands for the more durable, yet more expensive, California oak and tanoak pallets has suffered. In a pallet exchange system, the ownership of an individual pallet soon is impossible to discern. Therefore, the manufacturer has little incentive to buy a more expensive and durable oak pallet.

Under these conditions, Cal Oak has had difficulty selling pallets and shook at a profit.

Cal Oak's Response to Market Conditions

From the mid 70s into the 80s, Cal Oak's strategy was to saw black and white oak to recover upper and lower grades, while tanoak and cottonwood and madrone were sawn mainly for pallet shook, with upper grade recovery minor. Upper grade lumber was sold to small secondary manufacturers who could efficiently cut their required dimensions out of Cal Oak's basic product. Recovery of pallet shook was desired for use in Cal Oak's pallet line and for sale in a relatively strong market.

In 1984, the slump in the oak pallet market and lack of growth in upper grade sales led to major changes. In an attempt to increase the economic viability of lumber production, goals were set to lower production costs, reduce the output of industrial grade lumber, and increase the value and demand for upper grade lumber products.

Production Changes

Prior to 1984, Cal Oak had operated 2 mill shifts, largely milling low grade logs which yielded mostly pallet grade lumber. In April 1984, 1 mill shift was eliminated, and sawlog quality standards upgraded. Log grade sawlogs were now split for firewood. This new strategy resulted in a decrease in the recovery of low grade lumber, with a corresponding increase in upper grade yield. Lumber production per shift increased by almost 50 percent.

The increasing value of firewood during this period aided in the change, for those logs no longer considered sawlogs could now be split profitably.

In 1985, after 10 years of building pallets, the pallet assembly line was shut down and later dismantled. In its place, a resaw was installed to improve grade recovery and sawmill production. A planer was added to surface upper grade lumber.

The Door Program

In 1984, Cal Oak was approached by a large door manufacturer to provide the material for a rail-stile door made almost entirely from California black oak. By 1985, most of Cal Oak's upper grade production was earmarked for that purpose. In order to provide the many parts needed to assemble the variety of sizes and patterns of doors, a cutup/rip line was installed, where defects are "chopped out" of standard lumber to produce smaller, clear boards cut to a specific dimension.

New Uses for Black Oak--With this door program came innovations. Specially cut oak boards were sliced into veneer by the door manufacturer. This veneer was adhered to an engineered pine core to produce the stile and rail components of the door. After trial and error with gluing procedures, glued solid oak panels were mass produced to become the solid panel portion of the door.

Edge band and ovolo was sawn to complete the door components. In addition, all parts such as jambs, casing, and moulded trim, were to be supplied by Cal Oak. Cal Oak experimented with different cut patterns to find the most attractive and stable.

Results--From a technical standpoint, the program to enter the door market with California black oak was successful. It was a "natural", seizing the positive characteristics of the species, while minimizing the negative influence. However, factors unrelated to the properties or acceptance of the oak, nor to Cal Oak's performance, have since curtailed this program.

In this instance, the reliance of Cal Oak upon the commitment of one large customer, and the use of large amounts of capital resource and production in expectation of fulfillment of that commitment, proved to be highly deleterious. Cal Oak, while resolving to avoid new "eggs in one basket" situations, has had to find ways to reduce the negative impacts of the curtailment of this program.

Expansion of the Product Line

Over the last 3 years, Cal Oak has made many efforts to extend the use of native hardwoods to products which have a higher end value than lumber, or which complement the lumber and increase sales by meeting the more complex material requirements of secondary manufacturers and builders.

Rotary Cut Veneer--An experiment to produce rotary cut veneer from California black oak was initiated in the summer of 1985. Logs were chosen for their apparent suitability to be rotary cut and shipped to an Oregon veneering plant. They were peeled without any problem attributable to wood properties or log form. The veneer slices were sorted and glued both to a medium density fiberboard core and a plywood core.

The operation was generally successful, but the grade recovery and corresponding value of the veneer was not sufficient to continue on a regular basis. While this attempt to create a veneer product which would complement black oak lumber failed on economic grounds, we have found that certain substitute veneers are quite compatible with California black oak lumber, when juxtaposed in furniture or cabinets.

Flooring--Although black oak, madrone, and tanoak have desirable characteristics for flooring, and have been used for that purpose, the availability of flooring from these species has been sporadic. As a result, the consistent use of and demand for native hardwood flooring has never developed.

Since 1984, Cal Oak has had flooring manufactured by contract from blanks cut at Cal Oak, making these products consistently available in the product line. Offsite millwork is costly, but the manufacture and selling of flooring allows Cal Oak to utilize short clear cuttings and narrow width boards generated by its cutup line, and to provide a product which complements and increases sales of its lumber. Since tanoak and madrone are well suited for flooring, there is the potential that sales of these species can increase substantially.

Native hardwood flooring products now face serious price competition from eastern oak and other species.

Paneling--Cal Oak has experimented extensively with different patterns, widths, and thicknesses for paneling and wainscoting, and has brought into its product line black oak wainscoting and paneling, manufactured under contract from blanks cut at Cal Oak. With the increasing importance of flooring and paneling, and to reduce manufacturing costs, a moulding machine will be installed in the spring of 1987.

Varying Thicknesses--The difficulty of kiln drying native California hardwoods increases greatly with increasing thickness of the boards. Until recently, Cal Oak's upper grade production was largely 4/4 lumber. Since furniture manufacturers need a variety of thicknesses, particularly 5/4, 6/4, and 8/4, this impaired the marketing of Cal Oak lumber. By mid-1986, the kiln drying of black oak boards of these thicknesses with acceptable losses was achieved through experimentation with kiln schedules. This increased variety of available thicknesses may let Cal Oak more competitive with eastern oak suppliers.

Secondary Manufacturing

The Wood Box--In 1986, Cal Oak launched a program to produce and sell a box made entirely from California black oak, designed specifically to complement Cal Oak's boxed firewood. Materials are supplied largely from #*1* and #2 Common black oak lumber, cut and ripped to eliminate unacceptable defects and to create the different components.

The intent of the wood box program is to integrate vertically and to diversify products, thereby using part of the production capacity created for Cal Oak's role in the door program. Also it hopes to create an internal demand for dimension stock without depending on performance by others. In producing the wood box, less desirable upper grade lumber which often does not sell well can be cut up and utilized, while creating an attractive complementary product to enhance the sales of Cal Oak boxed firewood products.

The wood box program has recently been expanded to include other types of decorative boxes, such as for wine, electronic accessories, and planting boxes.

The Market for Firewood

The growth in California's firewood consumption since 1974 is well known, although estimates of annual consumption vary. An analysis of California markets by Doak and Stewart (1986) notes that while native hardwood firewood is a premium commodity, it is minor in the total consumption, and substitute woods have entered the market as native hardwood prices have risen. A study of Bay Area trends by Gasser and Stewart (1985) indicates that overall demand may be stabilizing or declining, and that factors such as rainfall and consumers' perception of energy costs influence annual consumption.

Cal Oak's production and sale of firewood, once simply a means to be rid of residues and substandard logs, has grown with demand, and is now an integral and substantial part of the Company's business. Logs are actively procured to provide material for boxed firewood products, for splitwood sold in bulk, and for local retail sales.

Cal Oak's View of the Market

Prior to these recent analyses of firewood markets, Cal Oak has had to draw conclusions about market characteristics and make marketing decisions based upon observation and experience. These conclusions are as follows:

Consumer Objectives--The objectives of the California firewood buyer range from those depending entirely upon wood for heat to those enjoying the fire's aesthetic benefits. The latter consumer's concept of wood is as a convenience or luxury item, and cost has less interest or meaning to him.

Local Markets--Consumer choice on firewood type varies geographically, with the preference for hardwood firewood strongest in the Bay Area, Central Valley, and Sierra foothills. Buyers close to a wood source, particularly in rural areas, tend to buy the local wood is available, regardless of species.

Wood Quality--Consumers will pay a premium for wood that is dry, clean, and of good measure, rather than spend less for an unknown commodity.

Continuing Demand--Cal Oak has presumed a growing demand for native hardwood firewood. Consumption by urban, convenience oriented buyers is presumed less related to economic factors, such as the cost of wood stoves or other heating fuels, than is consumption by utilitarian wood users.

Response to Markets

Cal Oak's marketing strategy is to stress sales to urban consumers who purchase for convenience and aesthetics, while using less effort in selling wood for heating. Cal Oak's boxed firewood products are designed primarily to meet this urban demand.

Boxed Wood--Cal Oak's first boxed firewood product, made in 1976, was a 1 cubic foot mix of split oak wood and slab mill byproduct cut to length. The success in selling the box in grocery stores was a marketing breakthrough, since firewood sold by conventional means is messy and difficult to handle. The box provided a clean, easily handled product, simple to distribute and sell.

The boxed firewood market has grown to be very competitive. Adjustment and upgrading of the product line is a constant necessity, and Cal Oak currently has several sizes and types of product available. Marketing chores have in part been contracted to professional food brokers well versed in the arcane protocol of the grocery business.

Processing Considerations--The efficiency of the splitting operation is very important, due to steady increases in the costs of raw material, labor, and insurance. Cal Oak's method of buying raw material in log form requires conventional logging methods, and a part of the log, purchased by weight, becomes splitting residue with negative value. Both logs and split wood must be stored, which is costly. Thus, Cal Oak's material costs are higher than firewood producers who process firewood where trees are cut.

Cal Oak has attempted with only moderate success to make splitting more efficient with less waste, and to capture whatever waste is generated. This is one of the weakest aspects of our firewood business.

The Market for Chips

In the last 10 years there have been 3 major uses for pulp quality hardwood chips. Exporters buy both hardwood logs and chips for sale in the Far East. Domestic paper manufacturers use softwood chips, but buy some hardwood chips for specific uses. Recently, biomass energy producers have desired clean, burnable mill residues, including chips.

The current demand for pulp quality hardwood chips is low, and no major changes are expected. Although some exporting of hardwood pulp chips occurs regularly, there is no export demand for hardwood chips within Cal Oak's operating area. For several years, the Louisiana-Pacific paper mill in Antioch has used some hardwood chips, most recently eucalyptus. The demand for mill residues to fuel biomass powered energy plants grows incrementally with each new plant.

Cal Oak's Response--Cal Oak can produce chips both from mill residues and from small whole logs, independent of sawmill operation. From 1978 and 1981, whole logs were chipped in response to high export demand. Since 1981, the value of split firewood from a given log has been greater than that of chips from that log. Cal Oak makes chips only from mill residues and from parts of logs which cannot be manufactured into a firewood product.

Since 1985, a biomass fueled power plant in Oroville has been buying Cal Oak chips for fuel, providing an alternative to the sale of chips to the Antioch paper mill. The relatively low value of either use has made transportation costs the deciding factor in the end use of this material.

Efforts to market the hardwood chips in different ways have been minimal but do offer promise. Some potential uses for the hardwood chips include garden products, a mushroom growing medium, and barbeque fuel.

Other Byproducts--Cal Oak produces about 25 tons of sawdust and shavings from milling and planing operations each day. This material is currently sold to the nearby biomass fueled plant in a mixture of sawdust and chips. Some minor volumes are sold as mulch and as bedding for stables. As with the wood chip, other efforts to market this material have been few.

SUMMARY

Since its inception, Cal Oak has both reflected and facilitated a broad diversification of uses for native California hardwoods. The Company's evolution, from pallet shook mill to long term producer of high grade hardwood lumber and supplementary products, is the result of a striving to attain the highest value product from native woods, while making the sale of low value products and byproducts viable.

Recent actions by the Company have strengthened this trend. Major changes in production and manufacturing ability have favored high value outputs, such as dimension stock for hardwood doors, over low value products, such as pallets. Since 1984 concerted efforts have been made to increase the marketability of lumber products by providing a variety of lumber dimensions, black oak plywood, glued panels, and moulded products. An expanded use of oak, tanoak, and madrone for flooring and paneling has been accomplished.

The diversification of manufacturing capability and increasing vertical integration is likely to continue at Cal Oak. Improving the efficiency of production and increasing the physical recovery of residues and the end value of low grade products and byproducts will also be of high priority.

CONCLUSION

Cal Oak's experiences provide a unique opportunity to examine the practical aspects of large scale, multiple product utilization of native California hardwoods, and to draw conclusions regarding the nature of that enterprise.

The technical and economic feasibility of producing lumber from California hardwoods is well proven. However, there are few traditional applications for these woods. When marketing native lumber products for a given use, eastern lumber products usually must be displaced in the marketplace.

To compete with suppliers of traditional species, the California hardwood lumber producer must attempt to upgrade and diversify the product line so that the full range of products necessary for commercial applications is available to secondary manufacturers.

Over the long term, there have been large changes in the values of native hardwood lumber, firewood, and wood pulp chips. California hardwood processors must observe changes in the values of these and all other products potentially derived from native hardwoods, and must modify output of products to minimize losses or to gain new revenue sources.

The aggregate value of all the end products yielded from an operation like Cal Oak's is low. While some upper grade lumber and firewood production may be profitable, many of the products yielded are currently sold at a loss. The value of each product attained must be maximized.

A given hardwood log must be properly allocated to that use which will maximize the ratio between the value of the products derived and the cost of processing.

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California's Hardwoods--What Potential?[1]

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There is one thing that I have learned at this conference during the last 2 days. I have had a misunderstanding about hardwoods for the last 25 years. I always thought that the term "hardwoods" and "softwoods" referred to the relative characteristics of the wood. That does not appear to be true. I found out over the last 2 days that the "hard" in "hardwood" means something else completely. It is "hard" to grow' it is "hard" to sell; it is "hard" to count the rings and it is "hard" to get any consensus on how to manage hardwoods.

I would like to discuss tonight a couple of subjects that California Department of Forestry and fire Protection is becoming involved in and some initiatives that we are taking in marketing and utilization.

We have heard a lot about marketing in the last couple of days. The Forest Service, U.S. Department of Agriculture, had an item in their budget for fiscal year 1988 for about $5 million for a marketing effort. Unfortunately, it died in the final conference committee. They were given $100,000 to work with National Forest Products Association and came up with a marketing program.

Although this program is not specific to hardwoods, it will have some spin-off benefits. Regardless of the loss of the Forest Service funds, CDF is undertaking a major effort. Under our California Forest Improvement Program, we are currently working on a marketing program. We just completed the first phase with a report by the Sierra Resources Consulting Group entitled, "Marketing California's Forest Product." The primary objective of that study is to identify ways in which CDF can assist the California Forest Products Industry to increase sales and profits, hence to bolster economic development in the State's.

The project has three key elements. The first is an identification of the existing and potential markets for California's wood products. The second is the identification and assessment of the way in which CDF could productively involve itself in marketing. The third is the identification and documentation of the detailed steps for implementing the most promising programs identified in the first two steps. A coordinated statewide effort in a marketing program for certain of the State's forest products could produce some substantial benefits for the forest products industry in the State's rural areas. The are specific opportunities for export markets which we are investigating. I recently learned that the State of Washington has a major marketing effort called the Evergreen Partnership. It's a cooperative effort among state government, private industry and others, and they are very optimistic that the marketing effort will provide substantial benefits for the State of Washington. You can assume that the State of Washington would like to get into our markets. So if other states are getting into this process, I think California must do like-wise to remain competitive.

Our first major activity under this marketing program is a symposium which will be sponsored by CDF on March 16, 1987, in Sacramento. This marketing effort is not designed specifically for hardwoods. It incudes [sic] all forest products. But I guarantee that after this symposium and with some of the things were have learned and heard here is these 3 days, we will be making some major efforts in the hardwood area as part of that marketing program.

The second initiative I want to talk about is utilization. We have several excellent papers this afternoon on the various problems involved with utilization.

Both of the keynote speakers, Harold Walt and Zane Smith, made reference to utilization. Zane Smith said that hardwoods were hard to mill. Hal Walt said that hardwoods were hard to dry. Both of these statements are true when we are dealing with a softwood mentality that currently exists on the West Coast. However, I contend that neither of those statements are necessarily true about eastern hardwoods. Hardwoods in California represent different kinds of challenges, but the technical issues are probably no more complex than those of the east. I think that was affirmed by some of the speakers we heard this afternoon in the utilization session.

[1]Presented at the Symposium on Multiple-Use Management of California's Hardwood Resources, November 12-14, 1986, San Luis Obispo, California.

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The Board of Forestry has been looking at the hardwood issue for several months before this symposium. During the Board of Forestry field trips, we learned that hardwoods, in some areas, are not being managed properly. Part of the reason that I think we have seen some of the misuse or possible abuse of hardwoods is that they have as relatively low economic value. The same thing happened to softwoods in the early part of this century in California, particularly Douglas-fir. when a forest product or any kind of a natural resource product has a relatively low value, there is not a great deal of respect for its value and consequently the use or misuse of the resource can take place. There is no great incentive to manage or grow it because it has marginal value. Some of the activities we see in the foothills of the Sierra where hardwoods were being cleared is due to this low value. Hardwoods were incidental to other land management objectives. The premise is that if these hardwoods had higher value, they would be better managed. If the hardwoods had an intrinsic or economic value, landowners would manage those woods. One of the purposes of our utilization and marketing programs is to bring the values of those hardwoods up high enough so that they could be managed.

I believe that East and Midwest had some of the same problems. Probably 50 or 60 years ago, their hardwoods were considered low value. They developed techniques, markets, and processing, and now have high value products. You certainly don't see them treating their hardwoods as we treat many of ours. In California, most of our madrone and tanoak stands in the conifer hardwood forest are not being utilized. Some outstanding trees are being pushed over, cut, poisoned or otherwise destroyed. They are viewed as a weed specie because our foresters have a softwood mentality. Landowners have the softwood mentality and they don't realize that there may be some potential value in those woods.

To prepare for this talk, I did some extensive market research. Before coming to San Luis Obispo on Tuesday, I stopped at our local Lumberjack store. They have three native American species of hardwood in their lumber rack: red oak, birch, and red alder. The red oak and birch I would assume came from the East and Midwest. The red alder, I assume, came from the Pacific Northwest.

This extensive nonscientific marketing survey came to a very dramatic conclusion. Red oak, in the Lumberjack store, sells for $3,500 to $4,000 per thousand board feet. Birch sold for $4,200 per thousand board feet. The alder, that species that we try to kill, was selling for $1,600 per thousand board feet. I looked a [sic] the rest of the lumber racks. They had redwood, pine, fir, and all kinds of other softwood species. The three hardwood species, disregarding the mahoganies and some exotics, were the highest priced pieces of lumber in that entire store. I believe that our California hardwood species could command these prices if marketed properly. The average buyer would purchase California black oak, or other hardwood species, if they were available. They would probably even buy tanoak and madrone if the price was right.

To make my point, I'd like to use a few statistics out of a report done by Bill Sullivan of Humboldt State University in a report entitled, "The Economic Potential of Tan Oak Timber in the North Coast Region of California."

The report does two things. First, deals with the quality and quantity distribution of tanoak logs and lumber in the north coast; second it represents an overview of the economics of the hardwood industry in the State on Michigan for comparison to what could occur potentially in California. I know many of you would say that there can be no direct comparisons between Michigan and what might occur in California because there is no comparison between the woods or the economic conditions. There are significant differences but the potential for some of the species in California is great. The real difference between softwood and the hardwood industry in California, according to Sullivan, is the magnitude of the added value of the product. A dry surfaced softwood board leaves the region, wherever it's harvested and milled, as a final product. A dried surfaced hardwood board is a raw material for future manufacture which could be done within the region where it is grown and originally milled.

As we heard yesterday, California is the second largest furniture manufacturer in the United States. Most of that industry is in southern California because there transportation into California is the cheapest for all the wood that comes from the East. If we develop California hardwoods we could just as easily locate some of those furniture industries up in the more economically impacted communities in northern California.

In the Michigan study, for 1980, Sullivan found that about 200 million board feet of hardwood sawlogs were cut and they had a value at the mill of about $50 million. They employed about 2,500 people in that process. The value added in secondary manufacture in the State amounted to $750 million with 28,000 jobs. That is a fifteenfold increase in the value and a tenfold increase in jobs. Those increases are phenomenal.

There are some great differences as I said earlier between California and Michigan. Michigan has about 28 billion board feet of inventory of hardwoods. The four northwestern counties of California, in the conifer-hardwood mix according to Bolsinger, has about 7.5 billion board feet of hardwoods. Unlike California, Michigan destroyed most of their conifer forest and did not replant it.

About 70 or 80 years ago, they decided to manage their hardwood forests and develop a hardwood industry. Michigan is actually working with lower grade sawlogs than we have in California tanoak. Michigan has a well developed hardwood technology and process in place. Ours is almost nonexistent. However, it's been proven that it can be done in California. Michigan is using well known and accepted species. Tanoak has a bad reputation for drying, for market acceptance, and for consumer acceptance. Past efforts at getting a viable tanoak industry have failed. However, tanoak has potential as a cabinet wood and as we heard today it has physical characteristics that are about the same as red oak. Tanoak is a little bit stronger and harder and has a greater shrinkage rate. The average value for tanoak lumber in Sullivan's study was $406 per thousand board feet, while red oak was selling at the time for about $725 per thousand board feet in Michigan. Values for tanoak are somewhat speculative since there is no accepted market. Cal Oak of Oroville, the only scale hardwood mill in California, in 1984 quoted some prices of $800 per thousand board for finished tanoak and $1,200 per thousand board feet for black oak.

We heard yesterday about the softwood mentality in the west. The industry here is geared to large volumes and high production rates. The softwood mills in California have a capacity of 30 to 150 million board feet per year. Hardwoods are difference. The mills, at least in the East, are usually very small, about 5 million board feet a year. This is truly, as Zane Smith said the other day, a cottage industry.

In California, we are faced with making a noncommercial species into an asset. According to Sullivan, a 10-inch tanoak log is superior to a 10-inch redwood log in lumbar value and far superior in the upper diameter classes. Now in terms of gross revenue per thousand board feet, tanoak offers much greater potential than second growth conifers. You will again note that I said potential. It has no real value at this time, but it does have potential.

One of the most significant problems lies in the market acceptance, or even in the awareness of the existence of west coast hardwoods. Most manufacturers are unaware that they grow here. we do have some excellent species. The dominant in California is California black oak, followed by tanoak, Pacific madrone and California laurel.

All of these species and several more at one time paneled the interior of the forestry building at Humboldt State. They were truly beautiful woods. I think--market acceptance aside--if people could see those woods in their finished state, in paneling or furniture, there would be market acceptance. I think all of these prejudices we have are probably ours and not the consumers.

I'm going to conclude with a little biblical proverb. In the opinion of many philosophers, an important part of our contemporary environmental problems are derived from the injunction stated in the sixth chapter of Genesis. "Go, multiply, and subdue the earth and take dominion over every bird of the air and every fish of the sea and every living thing that moves on the surface of the earth." That's been a tenet of western philosophy for the last one thousand or so years. I think with our current sense of awareness, if Genesis had to be rewritten, it might be more modestly put as follows: "Go and multiply with caution-bearing in mind the carrying capacity of the land and seas of the earth. Take a responsible dominion over the renewable and the nonrenewable resources of the earth-remembering that the health and prosperity of the people will be determined by the sustainable productive capacity of the lakes and streams and the fields and forests and the oceans of the earth."